A Low Cost K-Band Safety Warning Radar Receiver System

M.C. Tsai, C. Autio, M. Batten, M. Gagne, T. Kvenvold, C. Papadopoulos, B. Ricker, S. Sarkar and A. Perlowski

Whistler Corporation, Chelmsford, MA 01824

Abstract - A low cost K-band safety warning radar receiver system has been developed to receive highway hazard-warning messages transmitted from a newly developed Safety Warning System. This paper describes a radar detection scheme, which includes down converter, FM detector, microprocessor, and analog control circuits, intended for the K-band transmitter.

Introduction

As more and more military technologies are being transferred to commercial/consumer markets, one of the technologies that involves microwave electronics is the radar transceiver. Recently, RADAR[1] has developed a Safety Warning System™(SWS) transmitter through Georgia Tech Research Institute(GTRI). The transmitter sends out K-band signals which carry hazard warning messages that include from "Work Zone", "Emergency Vehicle Approaching", "Train at the Crossing", etc. to "School Bus Loading/Unloading". It brings to today's motorists one of the benefits promised by Intelligent Vehicles and Highway System (IVHS).

In responding to the potential benefits, a K-band safety warning radar receiver system has been developed. The receiver has to be low cost, small size, and readily installed in motor vehicles. This paper describes the receiver. It gives a system overview, and goes in detail about the frequency conversions and VCO. The microprocessor signal analysis is also explained. Finally, test results are presented and a brief summary is given.

System Overview

The K-band safety warning receiver includes a front-end down converter, an IF FM detector, a microprocessor, and control analog circuits, as shown in Fig. 1. A K-band signal is

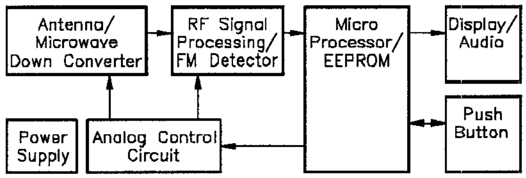


Fig. 1 System Block Diagram

received through the horn antenna and transformed to a microstrip circuit. The signal is converted to the first IF frequency in the 1 GHz range. The IF frequency is further converted to a second IF frequency, 50 MHz. An FM detector chip amplifies the signal and converts the signal to S-curves. The microprocessor controls the VCO, interprets the signals, and sends messages to the display. To achieve the lowest cost possible, the microwave circuit is laid out on a soft Teflon based substrate. Low frequency and digital circuits are laid out on a printed circuit board (PCB). All components, except two diode chips, are surface mounted using surface mount technology (SMT).

Microwave Down Converter

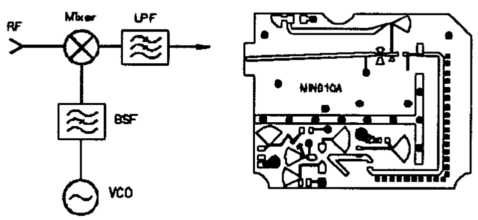
The K-band down converter, Fig. 2, includes a varactor tuned X-band VCO, a mixer, a band-stop filter, and a waveguide horn antenna. The antenna is a ridge waveguide horn which transforms the electromagnetic wave impedance from 377 Ω in the air to a 50 Ω system in the microstrip. The antenna gain is about 15 dB.

The VCO includes a packaged GaAs FET of 280 μm gate periphery with 0.5 μm gate width. The FET is self biased with matching patterns on the gate and drain. The frequency tuning is achieved through the resonance circuit on the gate, which includes a tuning GaAs varactor, and a shorted transmission line as the

TU 4C

0-7803-3246-6/96/$5.00 © IEEE

1996 IEEE MTT-S Digest



Schematic Block Diagram – Microwave Down Converter
Fig. 2

inductor. The output power of the VCO is about +10 dBm, with a tuning frequency ranging from 11.2 to 11.8 GHz.

Two types of mixer circuits have been used. One utilizes a single-ended Schottky mixer diode, which with proper biasing, can achieve about 10 dB of conversion loss. In this case, it is a single-ended sub-harmonic pumping. The other uses an anti-parallel mixer diode[2]. In this case, the two mixer diodes are 180° out of phase. It achieves a conversion loss close to fundamental pumping, about 7 dB, and it also suppresses the second harmonic of the VCO output power. This conversion loss determines dominantly the sensitivity of the receiver.

The band-stop-filter between the VCO and mixer not only rejects the input K-band signal, but also prevents the harmonics of the VCO from reflection from the mixer. It improves the detection sensitivity and tuning frequency slope.

RF/IF/Video

There are several important system attributes controlled by the RF through Video portions of the SWS receiver. These attributes include minimum system noise figure, signal acquisition time, shielding from external signals, freedom from spurious responses, size, and cost. These functions are achieved by the block diagram shown in Fig. 3.

The LNA is an SMD MMIC. Silicon is used for a 2.5 dB NF at a 1st IF frequency up to 1 GHz and GaAs is used for lower NF or a higher IF frequency. Cost and size objectives are achieved by selection of the proper wireless devices already mature and in high volume production.

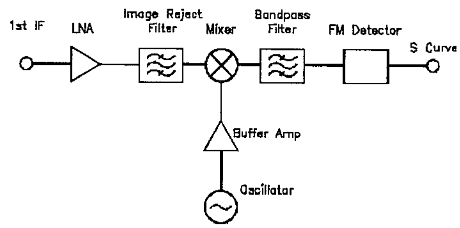


Fig. 3 Schematic Block Diagram – RF

The image reject filter is comprised of lumped elements using miniature chip inductors from the cellular phone industry. It prevents the image noise from the wide open front end from reaching the second mixer and folding into the 2nd IF.

Pre-detection noise bandwidth is limited by conventional band-pass filter and the Q of the quadrature detector network in the FM detector circuit. The Q of these circuits also limits the sweep time. There is a compromise between lowest noise bandwidth and highest sweep rate. Sweep rate determines signal processing time. A pair of output signals, or S-curves, are obtained by sweeping a CW signal down across the quadrature detector frequency, through zero beat and up the other side.

SWS signals produce a similar pair of S-curves but in that case the LO's are fixed in frequency and the SWS modulation excursion sweeps through the quadrature network. The S-curves are then processed with analog circuits or DSP software techniques.

Safety Warning Signals

The marker frequency of the safety warning signal is 24.1 GHz. Following the transmission of the CW marker, the message display code shall be transmitted. A bit representing the value "1" is encoded by the transmitter frequency starting 2.5 MHz below the marker frequency and sweeping linearly to 2.5 MHz above the marker frequency. A bit representing "0" is encoded by the transmitter frequency starting 2.5 MHz above and moving to 2.5 MHz below the marker frequency. The total frequency excursion is 5 MHz. The time period to sweep the signal frequency band is 0.5 msec, or a 2 KHz data rate.

There are two types of message formats accommodated by the RADAR's Safety Warning standard. One is the fixed-text message, which is a character string of up to 64 messages which resides in the radar detector memory. The other is the variable-length text message, which is a string character of up to 64 characters that shall be transmitted by the safety warning transmitter.

Software/Microprocessor

The receiver, upon reception of a CW marker, stops normal sweep and parks the VCO frequency to half of the difference between marker frequency and the first IF frequency. The sweep slope of the detected IF signal determines the bit to be either "1" or "0", which is processed and interpreted by the microprocessor. The fixed-text message is decoded by comparing the transmitted code number with a preset list of 64 messages residing in PROM memory. The variable-length text message is stored into the RAM memory as it is received from the transmitter. After the complete message has been received, the message will be translated and displayed or the variable-length text messages can be displayed on the LCD/LED dot matrix display. Fig. 4 shows a flow chart of the displaying messages.

The microprocessor also controls the VCO sweep. A sweep stop[3] algorithm has been implemented to improve the sensitivity.

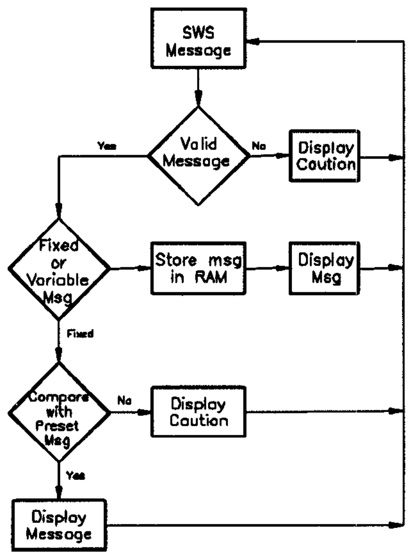
Test Results

The safety warning receiver system has been tested in an anechoic chamber. Fig. 5 shows test setup. The power density of the detected signal has been calibrated to include the antenna gain and path loss:

$P_{density} = P_{meas}$ + Antenna Gain - Path Loss, where Path Loss = $10 \, \text{Log}(4\pi \, r^2)$

The antenna gain is about 15.2 dB. The path loss is about 15.3 dB, given r = 1.65 m. Measured sensitivity is in the range of -95 dBW/m^2.

Fig. 6 shows the measured signals. Curve (a) is the modulated K-band signal in the time domain. Curve (b) shows detected S-curve video signal of the corresponding input signal.



Software Algorithm for SWS Message Display
Fig. 4

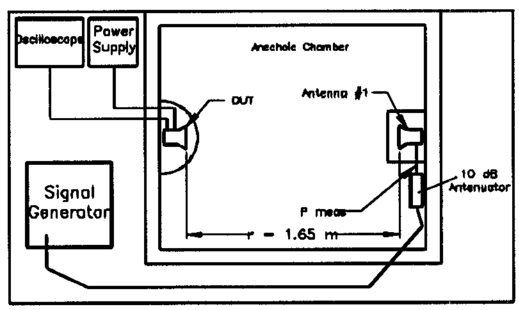


Fig. 5 Test Setup in an Anechoic Chamber

It indicates the K-band signal has been detected and an S-curve is generated. After that, the transmitter starts sending out binary signals. Curves (c) & (d) are expanded views of curves (a) and (b). Curves (e) and (f) are two digital output lines of the corresponding curves (c) and (d). Curve (e) represents a positive alarm line. Curve (f) represents a negative alarm line. It shows that during the initial 1 msec (2 bits) the alarm pulse is not ready to respond. After the initial time delay, typically about 4 msec, the alarm lines start to respond to the signals. If the negative pulse precedes the positive pulse, it represents a "0" bit. If the positive pulse precedes the negative pulse, it represents a "1" bit. The safety warning messages are received through the interpretation of these binary codings.

Summary

A safety warning radar receiver system has been developed. The frequency down conversion/detection scheme has been described. Test results showed that a low cost, highly sensitive SWS receiver is ready to be deployed on the road.

Acknowledgement

We would like to thank M. Burnell for support of the work. We would also like to thank B. Forsyth, S. Foss, and R. Babineau for drafting and testing. Also, we are grateful to J. Lee of RADAR and G. Greneker of GTRI for providing information of the transmitter.

References

1. RADAR is a non profit corporation based in Englewood, Florida.

2. M. Ventresca and M. C. Tsai, "An Active PsHEMT Sub-Harmonically Pumped Mixer", 1994 IEEE MTT-S Digest, pp. 1641-1644.

3. R.K. Mosher, US Patent 4,315,261.

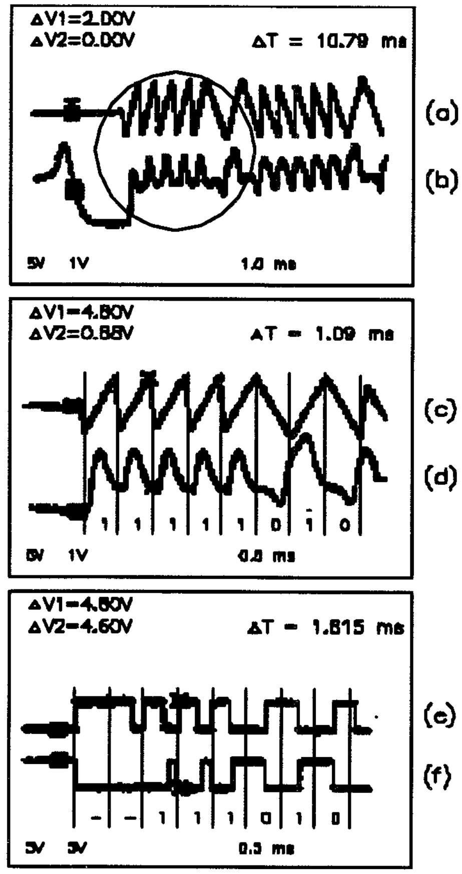


Fig.6
Meesured Signals: (a) & (c)Modulated Signal
(b) & (d) S-Curves, (e) & (f) Alarm Lines