Finline Technology for Millimeter Wave MEMs

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ABSTRACT

Recent development of finline 35 GHz MEM modules like Gunn oscillator, PIN switch, and filters at Nanyang Technological University will be discussed. The design tools and measurement equipments like Advanced Design System (ADS), High Frequency Structure Simulator (HFSS) and Vector Network Analyzer (VNA) are used extensively throughout the work.

1. INTRODUCTION

Millimeter wave has inherent properties of short wavelength, wide percentage of frequency coverage, narrow antenna beamwidth, good resolution and detection, ability to penetrate clouds and fogs, etc. and is good candidate for high speed and broadband electronics applications, such as wideband bluetooth, automotive collision avoidance radar, high resolution missile seeker, etc. Finline technology is able to integrate the millimeter active and passive devices together and is eligible to form the compact and light-weighted millimeter wave components [1,2]. Finline taper is similar to a ridged waveguide with dielectric backing as shown in Figure 1. It is inserted into a metallic waveguide to form a completed circuit. The sideview is shown in Figure 2. It requires précised electrical matching, chemical etching and mechanical milling. The matching requires negative impedance resonance for oscillator, low insertion and high injection losses in pass band and stop band for filter and switch. The chemical process requires fine line lithography in metal film development. The mechanical milling requires housing surface polishing and substrate residence positioning, etc.

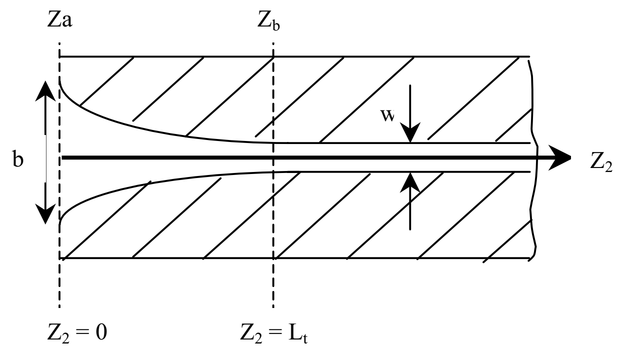

Fig.1 Finline taper

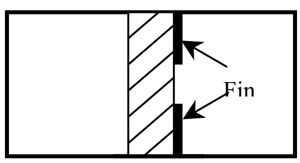

Fig. 2 Finline inserted into waveguide

2. MILLIMETER WAVE GUNN OSCILLATOR

An oscillator is needed in the transmitter to generate a carrier frequency of 35 GHz for modulating the digital signal that is to be transmitted. It consists of the following components: (1) the Gunn diode, (2) microstrip low-pass filter, (3) finline substrate, (4) tuning backshort and (5) metallic housing. The more commonly used substrate for the finline is the copper-clad microfiber-reinforced PTFE (trade name RT-Duroid) which has a dielectric constant of 2.22. In this project, the substrate used is Duroid RT-5880 with a thickness of 10 mils and a dielectric constant of 2.2. The metal film deposit on the substrate is gold-plated to enhance its conductivity. A typical type of low-pass filter is the series L and shunt C type of filter. It can be designed with either a maximally flat response (Butterworth filter) or an equal-ripple response (Chebyshev filter). Its design is based upon the normalized capacitance and inductance values. A microstrip low-pass filter can be realized by using deposited metal thin lines as an inductor and metal-substrate-metal as capacitor. The oscillator housing is made of brass with gold-plated internally. The dimension precision required a tolerance of 0.02 mm. The S11 parameter, which describes the gain of the Gunn oscillator, shows that the oscillator starts to resonate at a frequency of 35.3 GHz with a gain of 26.4 dB. The oscillator is biased at its maximum operating voltage of 4.5V and current of 540mA. Three Gunn diode samples are tested and the resultant frequencies are at 35.2 GHz, 37.4 GHz and 35.2 GHz [3].

3. MIXER CONFIGURATION

A popular finline mixer design is shown in Fig.3. The RF signal is coupled to the finline through a tapered transition and the LO signal is applied from the opposite end via a suspended substrate stripline bandpass filter. Because the RF voltage is applied to the diodes in phase, and the LO voltage is applied out of phase, this is a type of 180° hybrid mixer. All the mixer circuitries are in finline and bandpass filter; the waveguide serves only as a conduit for the RF and LO signals and as support for the dielectric substrate. The finline is a balanced transmission line, and the connecting point between the diodes is a virtual ground [4]. Because the electric field lines in the finline and bandpass filter are perpendicular to each other, there is no RF voltage between the bandpass filter and virtual ground at this point, so no RF signal is impressed on the bandpass filter. As long as good symmetry is maintained in the structure, the RF-to-LO isolation is inherently very good. For the same reason, no LO voltage is excited on the RF finline. The IF can be filtered most conveniently from the LO bandpass filter.

The design of the finline tapered transitions are based on the fundamental microwave principle that almost anything works if it is done gradually enough. The finline transitions are designed to taper, over a few wavelengths, from the waveguide to the strip transmission medium. As long as the finline curves are smooth and it is a few wavelengths long, the finline taper will work well.

Finline balanced mixer is a type of 180° hybrid mixer. As the electric field lines in the finlines and suspended substrate stripline bandpass filter are perpendicular to each other, very good RF-to-LO isolation is achieved. In addition, since the diodes are in series at the RF frequency and in parallel at the IF and LO, the impedance levels of the bandpass filter, diodes and finline must be in the ratio 1:2:4. [4] The impedance levels for suspended substrate stripline bandpass filter is 50Ω, 100Ω for each of the diodes, and 200Ω for the finline.

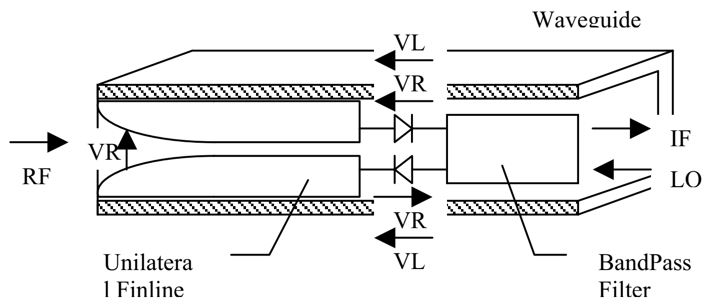

Fig. 3 Finline mixer configuration

The design procedure for broadside coupled suspended substrate stripline (BCSSS) capacitive coupled bandpass filter and is depicted in Fig. 4.

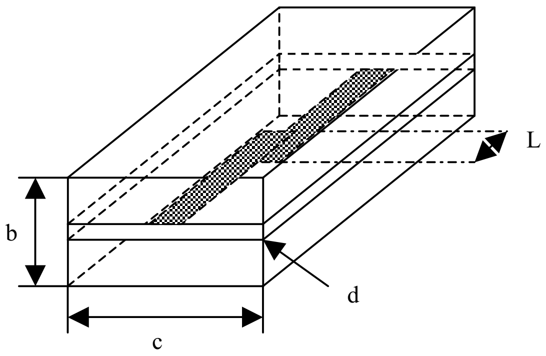

Fig. 4 Overlap Section Forming the Series Capacitance

This BCSSS capacitive-coupled bandpass filter design was simulated using HP HFSS. Fig. 5, 6 and 7 show the structure, S21 and S11 of this BCSSS capacitive-coupled bandpass filter respectively.

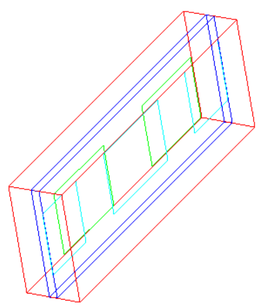

Fig. 5 Structure of Broadside Coupled Suspended Substrate Stripline Capacitive Coupled Bandpass Filter

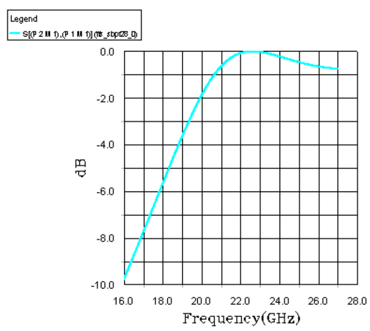

Fig. 6: S21 of Broadside Coupled Suspended Substrate Stripline Capacitive Coupled Bandpass Filter

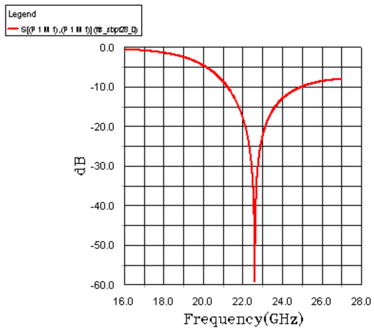

Fig. 7 S11 of Broadside Coupled Suspended Substrate Stripline Capacitive Coupled Bandpass Filter

4. PIN SWITCH CONFIGURATION

The PIN switch acts as a digital modulator with its TTL input and the Millimeter Wave i.e. 35GHz as the baseband data signal and carrier frequency respectively. Amplitude Shift Keying (ASK) will be the main means of transmission.

For operation as an on-off switch, the p-i-n diode is switched between two fixed bias states. For an ideal switch, the diode should present a perfect short circuit when forward biased (on state) and a perfect open circuit when reverse biased (off state). [5]

Driver-enhanced technique is used to optimize the diode equivalent impedance level and then the broadband performance.

The p-i-n diode impedance is dependant on the forward current driven through it. Therefore, a current driver is needed to adjust the p-i-n diodes' impedances for the control of the of the PIN switch.

The main component of the current driver is the 74LS04N chip. There are six input and six output pins. The TTL digital signal is fed into pin 1 of the chip as input. The output pin will either make the diodes forward biased or reverse biased depending on the logic level. (eg. Logic '0' is 0 volts while logic '1' is 5 volts). The driver also consist of current-varying resistor bank to provide the optimum impedance level during the duration in which the diodes are forward biased. Figure 8 shows a driver circuit.

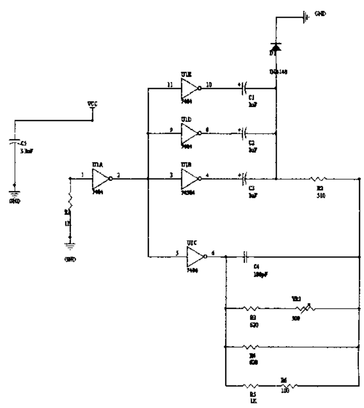

Fig. 8: A driver circuit

When the switch is ‘ON’, maximum signal transfer occurs. This in only when the shunt-connected diodes are reversed biased (during the ‘low’ state of the TTL input). The wave will propagate through the waveguide as modulation of the TTL signal and the carrier will occur. The reverse is true when the switch is ‘OFF’. The TTL signal (‘high’ state) will forward biased the shunt-connected diodes. The TTL signal passes through the input connector, via the diodes and leaks to the ground without modulating the carrier wave. Since no modulation occurs, the switch is ‘OFF’.

For the SPST PIN switch, it consists of a finline sections, a lowpass filter, and a launcher pad for the TTL signal. Three PIN diodes of same polarity with transmission spacing varying from 0.8mm to 1.9mm (λg, the guide wavelength of the fin-line was found to be 7.6915mm, and 1.9mm = 0.247λg, 0.8mm = 0.104λg) are shunt-mounted across the transmission line to reduce the impedance. [6] The two smooth taper arcs for both the input and output port will give a gradual transition from the impedance of 470Ω to 150 Ω transmission line system. Fabricated finline switch is shown in Figure 9.

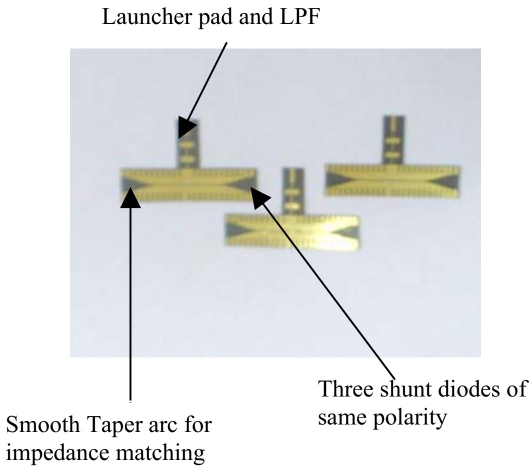

Fig. 9 Fabricated Finline PIN switch

5. ANTENNA DESIGN

Vivaldi tapered slot antenna (Fin Line antenna) can produce a wideband and end-fired radiation. Arrays of such antennas provide lightweight alternatives for focal-plane applications in satellite communication antennas involving beam shaping and beam switching. This design enables the user to integrate the feeds with mixer or amplifier devices on the same substrate that carries the antenna structure.

Such antennas are inexpensive to fabricate and could be useful as low cost and integrated antenna receiver/transmitter units. . They can be produced using photolithographic techniques, reducing the additional costs for a multiple-beam system.

An illustration of a Fin Line antenna fed from fin line in WR28 waveguide is illustrated in Figure 10.

The substrate material used is RT-duriod 5880 (εr = 2.22) of standard thickness of 0.127mm for Ka-band and above.

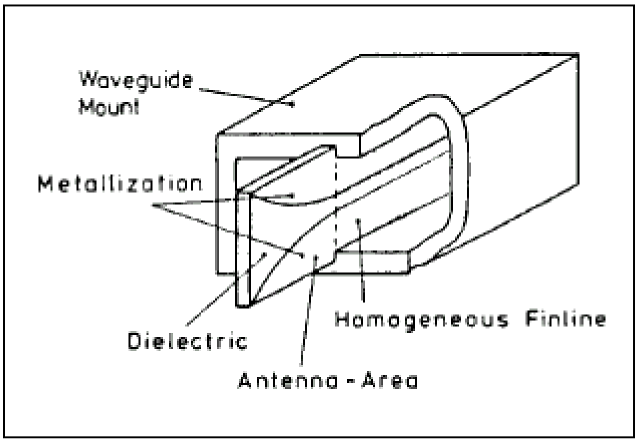

Fig. 10 A Vivaldi Finline antenna

A simulation system, XFDTD, was used to support the simulation process of the hardware during the unit testing and integration testing of the fabricated Vivaldi Antenna pairs.

The FDTD calculation of the basic antenna parameters can be obtained for a wide frequency band. The parameters include self- and mutual-impedance and admittance, gain, and main- and cross-polarization radiation patterns.

A Vivaldi tapered slot antenna based on Millimeter wave antenna fin line technique proposed by Beyer was being modeled and computed.

A rectangular cavity modeled by 24 x 12 x 330 FDTD 3D cells, each cell dimension 0.129 mm, was used for Vivaldi antenna design. The antenna is oriented with the waveguide axis parallel to the z-axis. It consists of four sides that are defined to be perfectly conducting (The tangential electric field components on these planes are forced to be zero).

Electromagnetic energy (at least over selected frequencies) is excluded from a cavity by the cavity walls. Subsequently, the fin line substrate is being modeled encapsulated in the cavity. The geometry of Vivaldi antenna is shown in Figure 11.

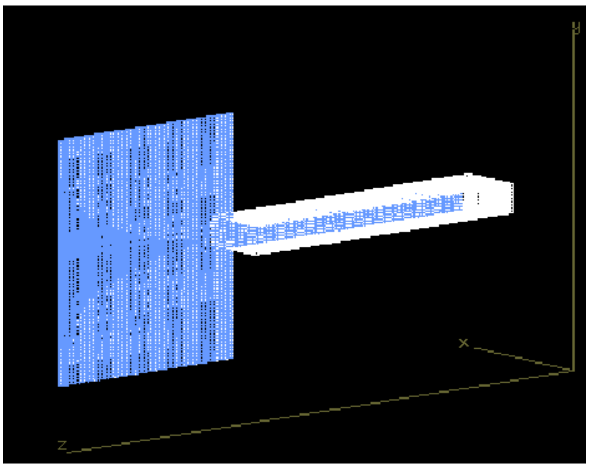

Figure 11 Geometry of waveguide and substrate in the FDTD computation space

5. INTEGRATION SYSTEM

A 35 GHz carrier is used to modulate a TTL signal fed into the SPST Switch. The TTL signal used is a rectangular pulse with frequency 1MHz which will give a 2MHz bit rate. The modulated signal is transmitted via a finline antenna. The receiving finline antenna will retrieve the signal and passed to a mixer. The fabricated finline antenna is shown in Figure 12. An LO signal with frequency 35.75GHz will also be fed to the mixer to remove the 35GHz carrier. Thus an IF signal of 750MHz (RF – LO) will be the output of the mixer. This IF signal will then be fed into a detector and the resulting retrieved signal will be displayed on the oscilloscope. The block diagram is shown in Fig. 13.

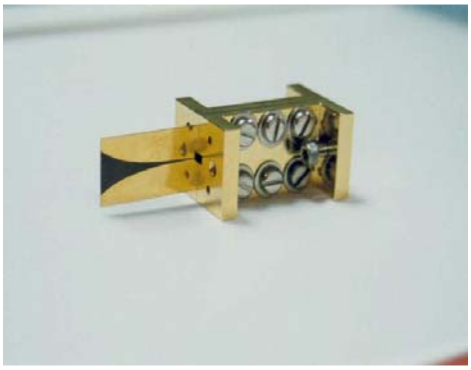

Fig. 12 Fabricated finline antenna

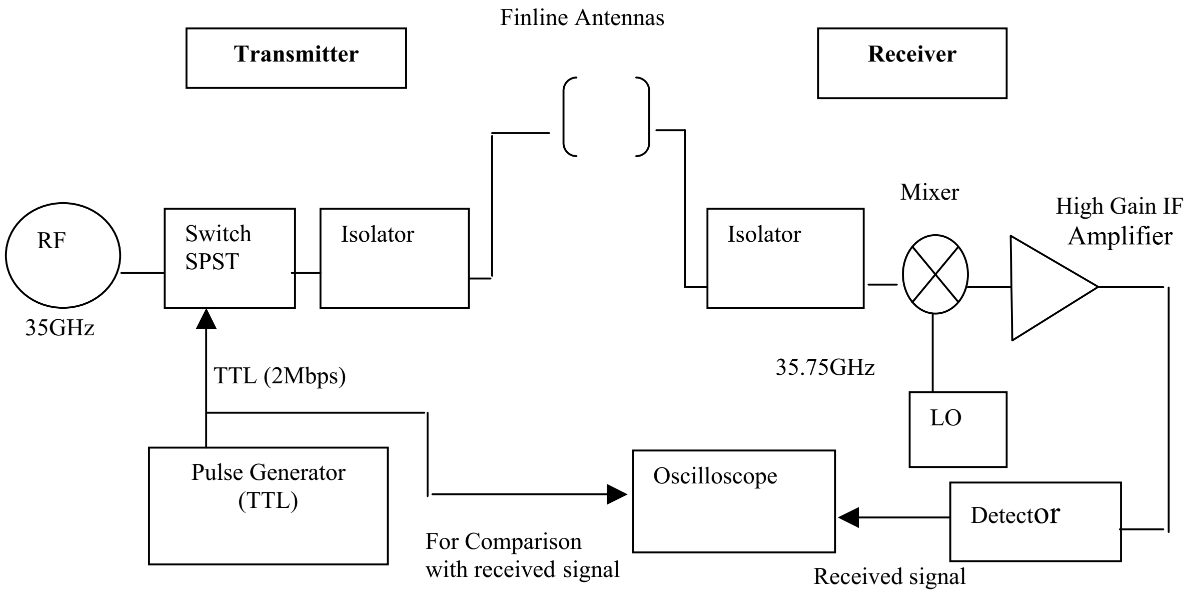

Fig.13 Block diagram of 35 GHz simplex data link test set-up

6. RESULTS AND CONCLUSIONS

Millimeter components like filter, mixer, switch, oscillator and antennas using finline techniques have successfully designed, fabricated and demonstrated. The combination of chemical etching, mechanical milling and electrical matching techniques make millimeter wave MEMs become technically achievable.

System integration test showed that a simplex MM-wave ASK link is set up using finline components. A rectangular pulse train with a frequency of 1MHz is used as TTL signal to drive the SPST switch. The voltage levels are between 0V and 5V. A frequency of 1 MHz will give a bit rate of 2Mbits/sec. A 35GHz carrier will modulate the TTL signal input to the SPST switch. The mixer gives an IF frequency of 750MHz before the signal gets demodulated by the detector. The detector is able to retrieve the transmitted TTL signal by removing the 750MHz intermediate frequency component. The received signal at the end of the detector is fed and displayed onto an oscilloscope as shown in Figure 14. A light weight, compact, easy to fabricate and low cost millimeter wave integrated system is then demonstrated.

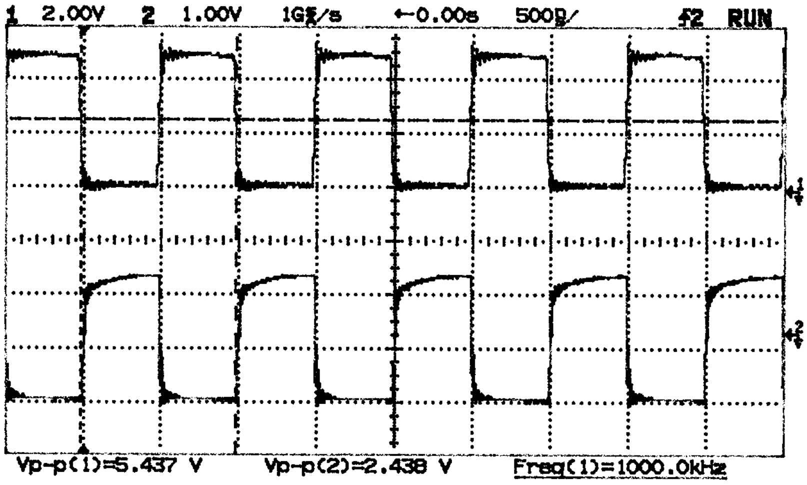

Fig. 14 Received data (bottom) versus transmitted data (top)

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