DIRECT MICROWAVE MODULATION AND DEMODULATION

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ABSTRACT

Direct modulation and demodulation techniques realized at microwave frequency are proporsed. Using microwave integrated technology, a linear FM oscillator and two types of discriminator for relay communication and linear amplitude modulator for UHF TV broadcasting are developed.

INTRODUCTION

Generally, microwave FM and AM signals can be obtained by up-converting FM and AM IF signals to microwaves. On the other hand, they are converted down to IF signals, and demodulated to the base band. However, a local oscillator and IF subsystem must be emploied. In order to simplify equipmnet, direct modulation and demodulation techniques at microwave frequency have been developed. Thus a direct FM osc. and a discriminator have been succesfully applied in a 1.5GHz modularized compact MODEM communicator, and a direct AM circuit has been applied in a low power compact UHF TV broadcasting station. Because the circuit chips are made on alumina substrate by thin-film technology, the equipment is simplified and performances of circuits are stable. Test experiment shows that excellent quality is acquired for the FM microwave TV signals transmission and UHF TV broadcasting using these circuit techniques.

Circuit Techniques

FM oscillator not only requires high frequency stability and pure frequency spectrum, but also needs high FM sensitivity and linear FM characteristics. Therefore, a positive feedback loop type oscillator has been designed. It consists of an amplifier, a BPF, a directive coupler, a delay line and two shifters as shown in Fig.1. It is known that the amplitude balanced condition for oscillation is easily satisfied. According to the phase balanced condition, it can be porved that the fequency deviation $\Delta\omega$ is proportional to the phase deviation $\Delta\theta m$ of the shifter, i.e.

$$\Delta\omega = -\Delta\theta m \;/\; Ta + Tf + Tc + Td + Ts \qquad (1)$$

where Ta, Tf, Tc, Td and Ts are the delay time of the amplifier, the BPF, the coupler, the delay line and the temperature compensation shifter, respectively. In the defined frequency region, it can be considered that all of these delay time components are constant. The key to increase frequency deviation of the VCO is how to achieve a larger phase deviation. The FM linearity depends on shift linearity of the shifter completely. A matching balanced voltage controlling shifter (VCS) which consists of a 90o 3dB-bridge and two identical variable reactors is applied in the VCO. The reactor is composed of a varactor C and a compensated inductor L.

The theoretically calculated curve (solid line) of phase angle θm at f=1.4GHz is shown

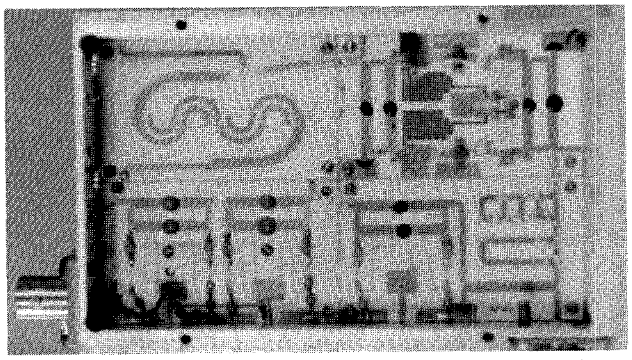
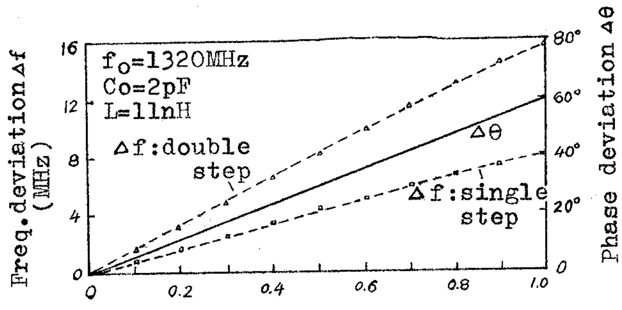


Fig.1. Photo of the FM osc.



Mod. Voltage (V)
Fig.2. Characteristics of the FM osc.

in Fig.2. Excellent linearity can be obtained, if the value of the junction capacitance of the varactor in zero voltage bias Co and L are properly chosen. For example, the mod. sensitivity of 60°/V can be acquired at Co=2pF, L=11nH. The experimental frequency deviation characteristics using single or double step VCS in FM osc. are shown as dash line. The FM sensitivity of 8MHz/V (single) or 16MHz/V (double) has been obtained. The non-linear distortion is less than 8%. The highest frequency of BB modulation frequency is more than 20MHz. The output power from coupler of VCO is about 2mW.

Because the balanced amplifier and VCS are applied in the osc. loop, and an n=3 Chebyshev BPF having a larger delay time Tf is adopted, the delay time Ta in amplifier which affects mainly the frequency stability of the osc. is only a small part of the total delay time (see equation 1). As a result, the short period frequency stability is less than ±2ppm. On the other hand, the medium period frequency stability is about ±1000ppm, because the temperature coefficient of dielectric constant on the alumina substrate is large. After using temperature compensation for the chip, the frequency shift is less than ±20ppm (0-50°C).

Good linearity and large AM index in microwave amplitude modulator are required. A passive network using two 90° 3dB-bridges and two phase shifters is proposed as shown in Fig.3.

It can be proved that the ratio of the voltage $|V_3/V_1|$ in the differential port 3 is

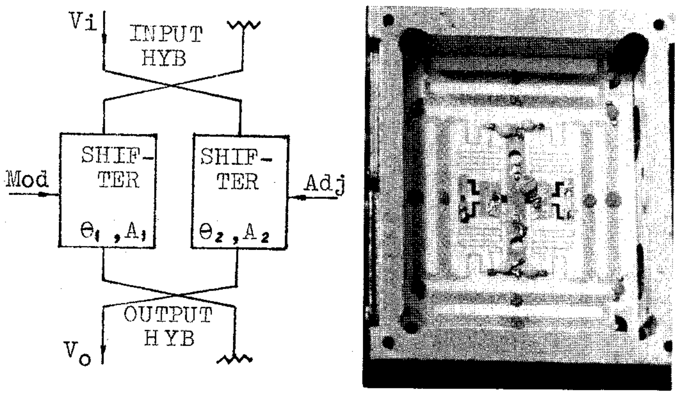
$$|V_3/V_1| = \sqrt{1+a^2-2a\cos\Delta\phi}/2A \quad (2)$$

where V_1 is the voltage at the input port 1.
$a = A_1/A_2$
A_1 and A_2 are attenuation of the compensated and modulated phasers, respectively
$\Delta\phi = \theta_1 - \theta_2$, θ_1 and θ_2 are phases of the two VCS.

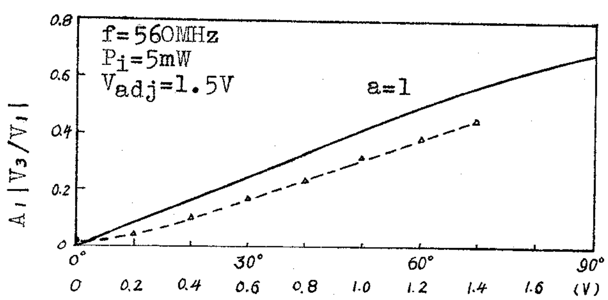
Therefore, if a = 1:

$$A_1 |V_3/V_1| = \sin(\Delta\phi/2) \quad (3)$$

The above equation indicates that the output V_3 can be approximately linear with the phase difference $\Delta\phi$ within the region (0°,60°), if attenuation in two ways is equal: a = 1. And if a = 1, the AM index is of the highest value. Therefore, AM linearity and AM index are related to quadrature performance of the two 3dB-bridges, to balance of the two ways and to linearity of the voltage controlling phasers. Fig.4 shows calculating and measuring results of the AM chip. Here, the controlling voltage is about 1Vpp. An AM index of 94% can be obtained at 560 MHz. The transitive attenuation is about 6dB.



(a) Circuit model (b) Photo of the mod.
Fig.3. Direct amplitude modulator



Mod.Voltage (Volt) or Phase diff.
Fig.4 AM characteristics

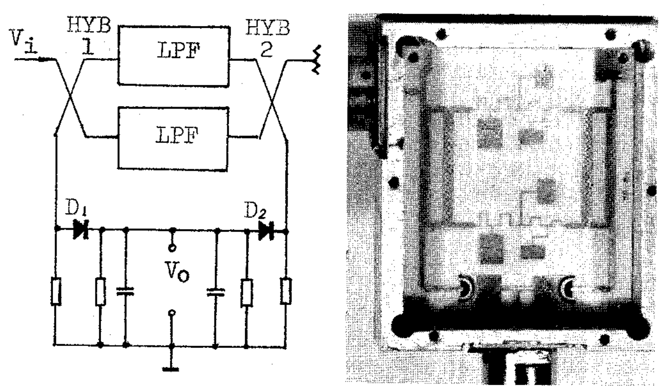
A slope discriminator and a phase discriminator in microwave have been designed. The microwave balanced slope discr. is composed of two 90° 3dB-bridges, two LPF having identical characteristics and two differential detective diodes as shown in Fig.5.a. It can be proved that the ratio of output voltage V_o to input peak voltage V_m in slope discr. is given by the equation:

$$V_o/V_m = K_d[1-(1+1/A)\cdot H(\omega)] \quad (4)$$

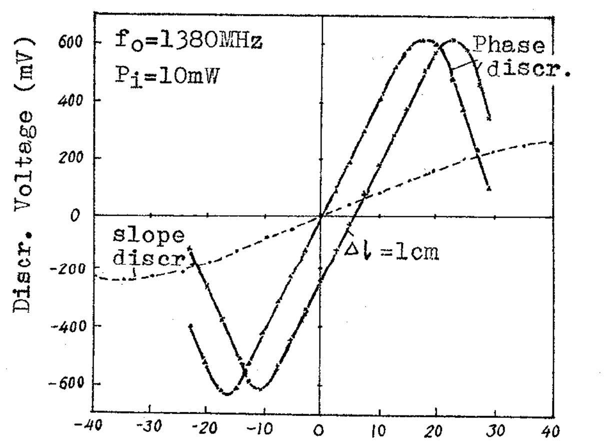
where $H(\omega)$ is the working transmission function of the LPF.
A is the working attenuation of the LPF
Kd is a coefficient of additional attenuation related to insertion loss of two 3dB-bridges and detective efficiency.

If the LPF were lossless: A=1, the center frequency ω_o of the discr. could be obtained by letting $H(\omega)=0.5$. Practically A>1, so the center frequency ω_o' can be solved from equation $H(\omega')=A/(1+A)$. Therefore, $\omega_o' < \omega_o$. In order to raise slope of the discr., the Cauer response LPF must be adopted.

The discr. has been made on a 4cm×5cm alumina substrate using microwave thin-film technology (Fig.5.b). The measuring S-type charateristics is shown in Fig.6(dash line). About 8mV/MHz discrimination sensitivity can be obtained at center frequency, when input level is 10mW. The non-linear distortion is less than 5% within ±4MHz.



(a) Circuit model (b) Photo of the discr.
Fig.5. Slope discriminator



Freq.deviation (MHz)
Fig.6. Discr. charateristics

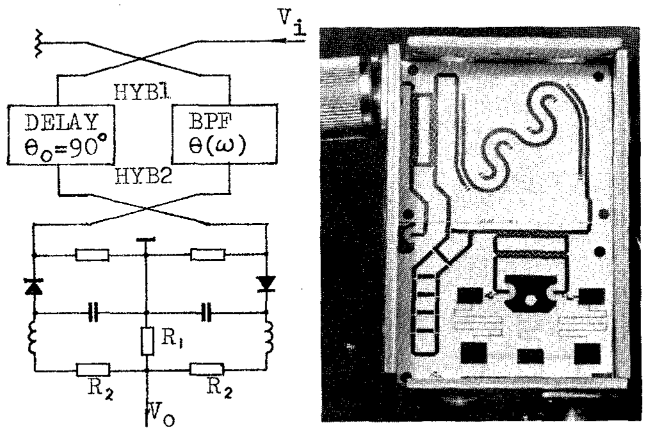
The microwave phase discr. consists of two 90° 3dB-bridges, a BPF, a compensation delay line and a differential detective circuit as shown in Fig.7.a. The ratio of output voltage Vo to input peak voltage Vm is given as follows:

$$\frac{V_o}{Vm} = Kd \frac{a}{\sqrt{1+a^2}} \cos(\theta - \theta_o) \qquad (5)$$

where a=Ad/Af and it is assumed that a<0.5. Ad is the insertion attenuation of the delay line. Af is the insertion attenuation of the BPF. Kd is a coefficient related to the loss of the bridges and detective efficiency of the detector. The phase shift of the delay line is $\theta_o=90°$, when length of line is $\lambda_g/4$(λ_g-wave length in the substrate). Morever, if the BPF has a Chebyshev respond, the phase-frequency charateristics is approximately $\theta = Ka \cdot SIN^{-1}(\omega - \omega_o)$, when $f<f_s$, the equation (5) can be expressed in the following fomula:

$$Vo/Vm = K(f-f_o) \qquad (6)$$

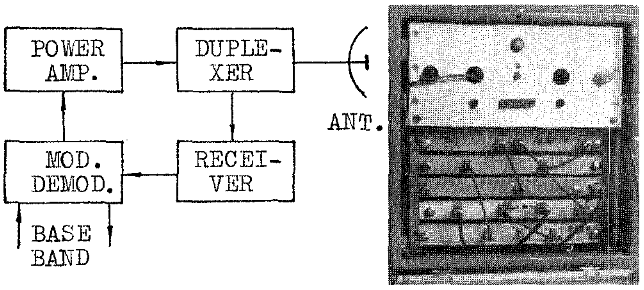
where, f_o is center frequency of the BPF. The phase discr. has been made on a 8cm×5cm alumina substrate as shown in Fig.7.b. This discrimination sensitivity is better than the sensitivity of the slope discr. Experimental discrimination characteristics of the phase discr. is also shown in Fig.5 (solid line). The sensitivity of the discr. of 25mV/MHz can be obtained, when input level is 10mW. The center working frequency of the discr. can be changed, if the length of compensation delay line is varied.



(a) Circuit model (b) Photo of the discr.
Fig.7. Phase discriminator

Application

Direct FM and discr. techniques mentioned above have been applied in a 1.5GHz low-cost MODEM communicator as shown in Fig.8. It consists of a direct mod. and demod. module, an AGC receiver, a power amp. and a duplexer module. The developed communicator has the compatibility of transmitting analog FM is used in multi-channel telephone or TV signal transmission. While the binary frequency-shift keying system is used in data communication. The outline of the communicator is shown in Fig.8.b. Four integrated modules are interconnected each other by semi-rigid coaxial cables. The modules are installed together with their power supply in a cabinet with a dimension of 30cm×27cm×31cm. The equipment is simple and reliable. Overall DC power consumption of the communicator is only 14 Watts.



(a) Block diagram (b) Photo of the outline
Fig.8. 1.5GHz compact communicator

Direct AM and loop osc. techniques have been applied in a compact UHF(at 560MHz) TV broadcasting transmitter module as shown in Fig.9. This module consists of a feedback loop osc., a linear direct amplitude mod. and a cascade balanced power amp. The output peak power of the trasmitter is more than 1 Watt.

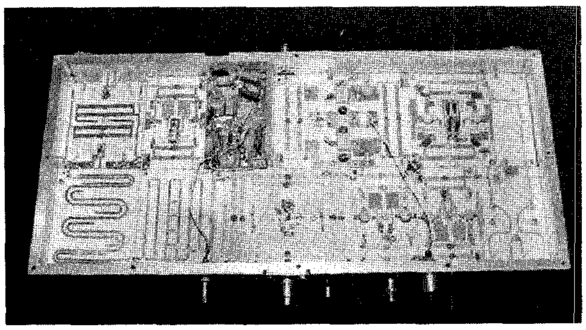


Fig.9. Photo of TV transmitter module

Conclusion

The developed communicator was tested in August 1981. The span between two stations in Fujian, China, is about 75Km. The experimental results show that the transmission quality of colour TV signals are very good. The UHF TV broadcasting transmitter was tested in December, 1982 in Nanjing. An excellent result can be obtained. From the discussion mentioned above, It can be concluded that the microwave direct FM, AM and discr. techniques are of value for microwave communication and UHF broadcasting. Obviously, the circuit techniques described in this paper will be designed at much higher frequency (for example at S or X band).

References

1. Kurakawa. K, "Design Theory of Balanced Transistor Amplifier", B.S.T.J, Vol.44, Oct. 1965, pp. 1675-1698.
2. Ron. Rippy, "A New Look at Source Stability", MICROWAVE, Vol.15, No.8, August, 1976,pp. 42-48.