A 2 W Solid State Transmitter for Short Range Data Communication at 60 GHz

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Abstract

Three 60 GHz powercombiners are cascaded to amplify a CW input signal of 2 mW up to 2 W. The maximum bandwidth is 1 GHz. In the first stage the incoming signal is split into two equal portions which are amplified by two reflection type Gunn Diode amplifiers. The combined output power (2o mW) of this stage is used to injection lock the two Gunn oscillators of the second combiner. The output of that (180 mW) serves as locking signal of the third stage, where two Ga As IMPATT oscillators (1.2 W each) are synchronized and powercombined.

In case of good balance of each combiner only one isolator between the stages is required.

Introduction

This paper describes set up and performance of a 60 GHz solid state transmitter that is part of a transmit–receive module of a short range, direct line of sight communication system. A network system of several transceivers should be able to communicate with each other at every time. If the line of sight is interrupted by stationary or moving obstacles like buildings or trucks, other transceivers have to serve as relay stations to keep the connection line. Such a mode of operation requires omnidirectional antennas which, unfortunately, have no gain. Hence, the transmitted power should be high for a certain transmission range.

On the other hand, to obtain very low probability of intercept (LPI) with undesired listening stations, the system takes advantage of the 60 GHz oxygen absorption line of the atmosphere. Also low transmitted power would limit the transmission range as desired. As a compromise between this contrary requirements, 2 Watt output power of the transmitter is chosen.

Multipath propagations cause interference fades which can be smoothed out by frequency diversity like frequency hopping or spread spectrum techniques. This requires broadband performance of the transmitter.

Another demands for broadband behaviour result from the mode of operation of the communication link. First, PSK Modulation is used to spread the spectrum being sensitive against residual FM or phase distortions. Second, the transmitter should be able to perform in a long puls mode (pulse duration: 200 µsec, duty cycle: single pulses up to 1:1) as well as in CW mode. Switch on time must not exceed 2 µsec. But rise and fall of the pulses cause phase chirp resulting in a residual FM.

For the reason that injection locked oscillators were used to produce the transmitted power, the following formulas [1] are valid to estimate the residual FM:

$$\frac{1}{2}\ \textit{Locking Range} = \Delta f_{max} = \frac{f_o}{Q_{ext}} \cdot \sqrt{\frac{P_{inj}}{P_{osz}}} = \frac{f_o}{Q_{ext}}\ \frac{1}{\textit{LockingGain}}$$

$$\Delta\phi = \arcsin \Delta f / \Delta f_{max}$$

and

$$\textit{residual FM} = \frac{d\phi}{dt}.$$

One can directly see, that a high locking range is necessary to keep the residual FM as low as possible. This can be achieved by low external Q of the oscillators and/or by high locking power.

A transmitter meeting the requirements mentioned above will be described in the following.

Set–up

Two types of mm–wave generating diodes have been available: GaAs Gunn–Diodes with an output power around 100 mW and GaAs IMPATT–diodes with slightly more than 1 W.

Consequently, the transmitter is set up of a chain of three powercombining stages (Fig. 1). The IF signal of a balanced upcon-

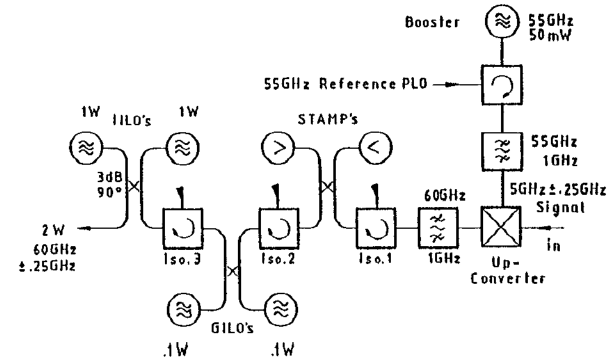

Fig. 1 Blockdiagram of the transmitter chain

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verter (LO: 55 GHz, 30 mW; signal: 5 GHz, 20 mW; IF: 60 GHz, 2 mW) is fed into the input port of the first stage, a hybrid coupler with two reflection type GaAs Gunn diode stable amplifiers (P_{out} = 10 mW each BW_{3dB} = 3,5 GHz, c. o. Fig. 2, abbr. STAMP). The signal is split into two equal portions that are amplified by the amplifiers and powercombined by the hybrid.

The output of this stage serves as locking signal for the second stage, where two Gunn oscillators are locked and powercombined (P_{out} = 100 mW each). In this manner, an output power of 180 mW and a bandwidth of 2.4 GHz as shown in Fig. 2 (abbr. GILO) has been achieved for this stage.

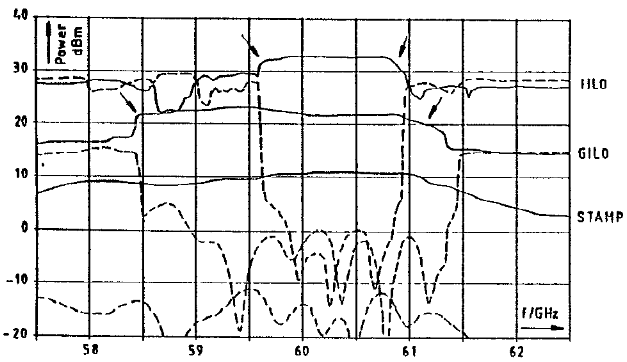

Fig. 2 Characteristics of the powercombiner chain
Solid lines transmitted power
Dashed lines backscattered power
STAMP = Stable amplifier
IILO = IMPATT injection locked oscillator
GILO = Gunn injection locked oscillator
Arrows: locking Ranges

For the 3rd stage, GaAs IMPATT diodes are used. Compared with Silicon IMPATT diodes, they offer a higher output power (1.2 W each) and a much better phase noise behaviour in the free running state as well as under locking conditions. The output power of this 3rd stage is more than 2 W. A locking range of 1 GHz has been achieved easily (Fig. 3, abbr. IILO).

In case of good balance and consequently high input to output isolation only one isocirculator between each stage is required. The isolation of this type of isocirculator has been optimized to 40 dB by using a sliding load to compensate the circulator leakage.

The backscattered power of one stage is typically 10 dB below its input power (c. o. Fig. 2). As a result, a decoupling of more than 50 dB between the stages can be assumed.

Results

The frequency of operation of the transmitter is 60.2 $\pm$ 0.25 GHz. Fig. 2 shows the output power versus frequency of the different stages. Solid lines indicate the combined power (Σ), dashed lines the power at the difference ports (Δ) which is the backscattered power of the different combiner stages. The arrows are marking the locking ranges $2\Delta f_{max}$. Results taken from Fig. 2 are listed in the following table:

	Σ	Δ	$2\Delta f_{max}$
STAMP	> 10 dBm	< – 10 dBm	B_{3dB} ≈ 3.5 GHz
GILO	> 22 dBm	< 0 dBm	≈ 2.4 GHz
IILO	> 33 dBm	< 0 dBm	≈ 1 GHz

STAMP Stable amplifier
GILO Gunn injection locked oscillator
IILO IMPATT injection locked oscillator

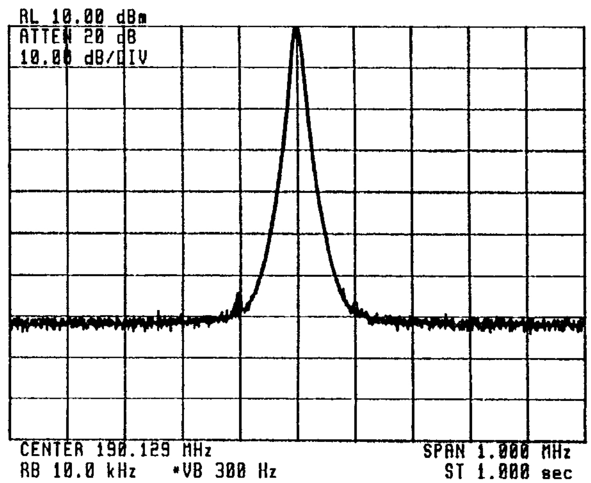

Fig. 3 Comparison of in– and output phase noise spectra

Fig. 3 shows a comparison of in– and output spectra of the transmitter at normalized power level. The locking signal was generated by a 60 GHz, high stable Gunn oscillator. No additional phase noise is visible.

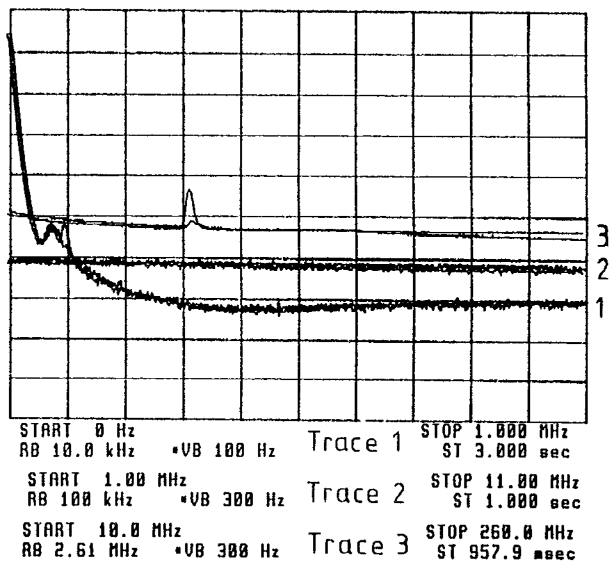

Fig. 4 Comparison of in– and output spectra far off carrier measured with a delay line discriminator

In Fig. 4 the demodulated phase noise of a injection signal (low noise Gunn oscillator) compared with the output signal of the transmitter is displayed. Injection frequency is 60.47 GHz, the upper end of the band of use. Here, up to 180 MHz off carrier, the spectra are nearly identical. For higher frequencies, the phase noise of the output signal degrades compared with the input signal. This phenomenon is quite well in accordance with the investigations of [2].

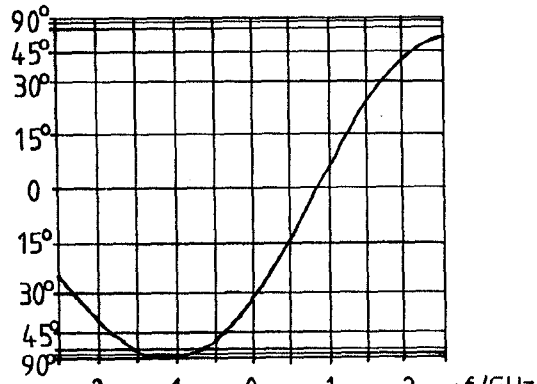

Fig. 5 Phase response of the chain versus frequency compared with a normal WR15 waveguide of the same length

Fig. 5 shows the phase response of the chain compared with a WR15 waveguide having the same length. The total phase shift over the full band of use 60.2 $\pm$ 0.25 GHz is 240°.

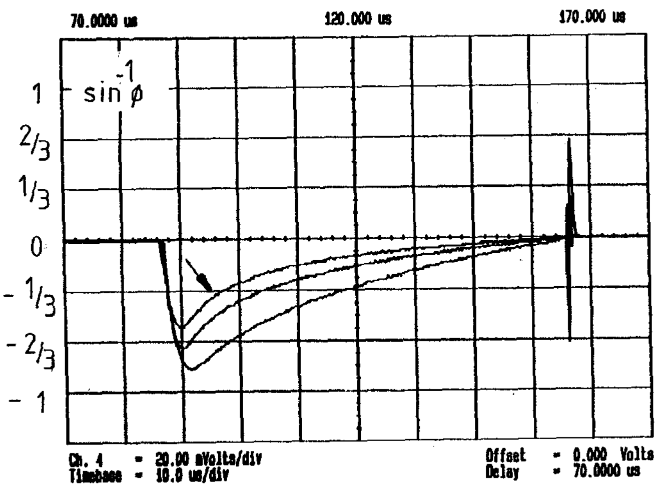

Fig. 6 Phase transient of the leading edge of the pulsed output signal at center frequency, lower and upper band edge.

Fig. 6 shows the phase transient of the leading edge of the pulsed output signal for midband, the lower and the upper band–edge. As expected, the phase starts at about 90 degrees (when the oscillators are starting to lock). Then, the phase declines to zero, when the thermal equilibrium is achieved. The residual FM at 10 µsec (see Fig. 5, arrow) is calculated as approximately

$$\frac{d\phi}{dt} = \frac{0,33}{10\mu\,\text{sec}} \approx 33\ kHz,$$

which can be easily tolerated by the communication system.

Fig. 7 shows a hardware photo of the breadboard model of the transmitter. Closer integration of the components will decrease the size significantly.

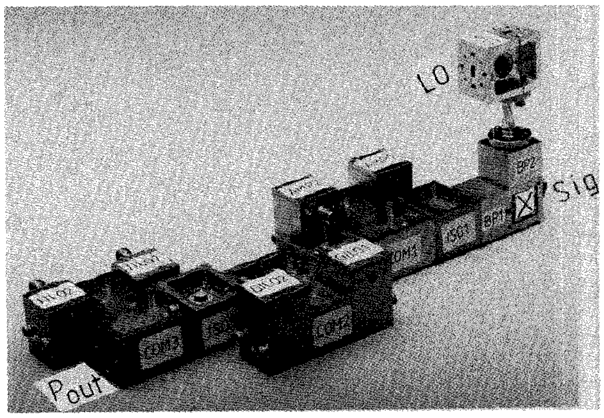

Fig. 7 Photograph of the complete transmitter chain including the up converter to produce the 2 PSK–modulated injection signal at 60 $\pm$ 0.25 GHz

Conclusion

A chain of powercombiners is used to amplify an input signal of 2 mW up to 2 W at 60 GHz. As a first stage, stable reflection amplifiers are used because the input signal of 2 mW would be unable to lock oscillators using the same diodes (100 mW) over a sufficient frequency range. Also, a combiner is required to produce the 200 mW power required to injection lock the final combiner stage delivering 2 W. In case of good balance of the combiners, only one isocirculator between the stages is required for sufficient isolation between input and output.

Without isocirculator, a locking range of about 0.8 GHz has been achieved. But because feedback between the stages cannot be excluded, the version with isocirculators has been preferred.

The different stages are made as broadband as possible to minimize phasedeviation caused by frequency change.

References

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[2] Ondria, J.C.; Hines, M.E.; Collinet, J.R.: FM Noise Suppression of an Injection Locked IMPATT–Oscillator. IEEE Transactions on MTT, Vol. 18 (1968) Nr. 9, pp 738–742