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Magnetron Transmitters for Millimeter-Wave Coherent Radar Systems

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The spatial-harmonic magnetrons with a cold secondary-emission cathode are promising oscillators for various millimeter-wave radar systems. Experience in the development and application of the transmitters on the basis of such magnetrons for coherent radar systems is summarized. Design approaches to the development of highly efficient transmitters for the frequencies of 36 GHz and 95 GHz with the power level of 30 kW and 4 kW, respectively, are discussed. Cloud Doppler radar systems based on such transmitters are described as examples of the applications of such transmitters.

1. Introduction

There are two main approaches to the development of coherent radar systems. The first of them lies in building such systems according to the so-called truly coherent scheme, where the transmitter is based on an amplifier driven by a highly stable oscillator. This oscillator is used also as a reference source for the receiver, in which case the measurement of the backscattered signal phase is relatively easy. Such systems provide fairly good clutter suppression, a high Doppler resolution, and give a possibility of introducing sophisticated methods of pulse compression. However, the lack of costs for an effective, high-power millimeter wave amplifier, especially for the frequencies 95 GHz and higher, constrains essentially the development of such types of radars intended for a long-distance operation. In order to tackle this problem, the second approach based on the coherent receiver technique can be used for the development of coherent systems. This approach deals with storing the values of the phase of the RF pulses emitted by the transmitter and comparing these values with those measured by the receiver. In this case, the transmitter can be based on a self-running oscillator, i. e. the magnetron. Besides, the recent advances in microprocessor development and digital signal processing allow the development of the coherent receiver systems with the capabilities similar to those provided by truly coherent systems.

In this paper we summarize our experience in the development of the millimeter-wave transmitters for the coherent radar systems based on the spatial-harmonic magnetrons with a cold secondary-emission cathode. Such magnetrons are superior to the conventional millimeter-wave magnetrons in such parameters as the lifetime, the average output power, the weight, and dimensions [1, 2]. However, until recently such magnetrons were used only in non-coherent systems [3, 4] and it was not clear whether they are suitable for application in coherent systems. The problem is that the quality factor of the magnetrons is not high, in which case it is difficult to achieve a high frequency stability. Next, the magnetrons with a cold cathode typically suffer from pulse jitter. Our studies have shown that using specially designed modulators one can successfully solve these problems. This approach has allowed us to develop the efficient 36-GHz and 95-GHz magnetron transmitters, which are promising for various coherent systems.

2. Magnetron transmitter design

We have found that among various possible schemes of modulators the scheme with partial discharge of the storage capacitor and the hard tube as a high-voltage switch is the most suitable for driving both 36 GHz and 95 GHz spatial-harmonic magnetrons with a cold cathode. The transmitter block diagram is shown in Fig. 1. The transmitter includes the following main parts: a high-voltage power supply, filament power supplies for the magnetron and the modulator tube, a driver for this tube and a controller. The low-voltage power supplies were built by using resonant technique to provide a high efficiency and to suppress interference. The high-power supply utilizes a flyback converter with a current feedback along with a voltage multiplier. Such scheme allows one to obtain the voltage ripple as low as 2 V with the output voltage of 20 kV and the output power of 500 W. The output stage of the hard tube driver is based on the two-pole scheme and provides the voltage swing of 1500 V with the rise and fall time less than 15 ns. All power supplies in the modulator are synchronized at the frequencies multiple to the pulse repetition frequency of the transmitter.

3. Transmitter characteristics

The above solutions enabled us to obtain the output transmitter pulses with a rather good shape and a negligibly small jitter. The intrapulse phase change during the high-power period of 200 ns pulses is about 10° and 20°, and the pulse-to-pulse frequency chirp is reproducible to about 100 Hz and 300 Hz for 36 and 95 GHz transmitters, respectively.

Typical build-up of the RF pulses of 95 GHz transmitters is shown in a photo in Fig. 2. This photo was obtained by superposition of 20 000 successive pulses. It is easy to see that the pulse jitter is less than 2 ns. The jitter occurs only at the initial stage of the pulse formation. A photo in Fig. 3 illustrates the power spectrum in

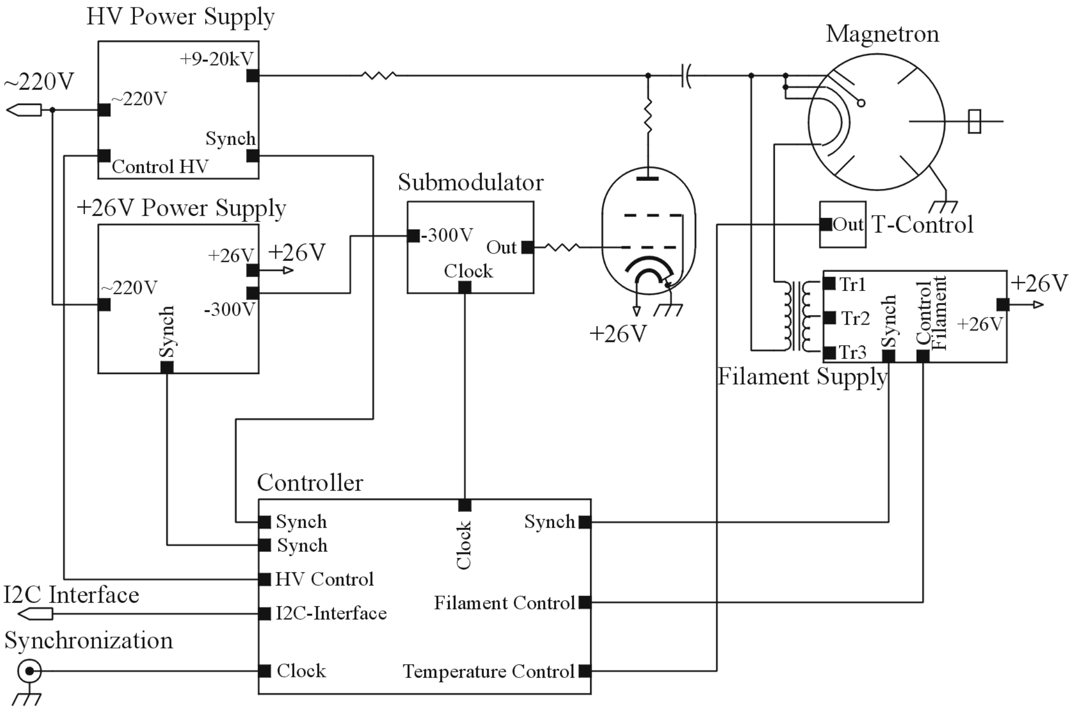

Fig. 1. *Block diagram of 36 and 95 GHz magnetron transmitters*

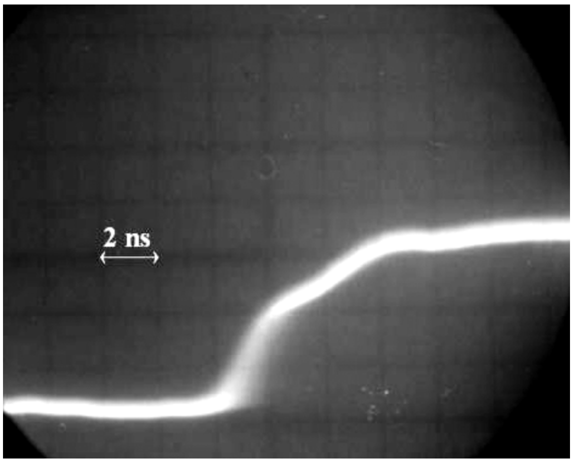

Fig. 2. *Build-up of radio frequency pulses of a 95 GHz transmitter*

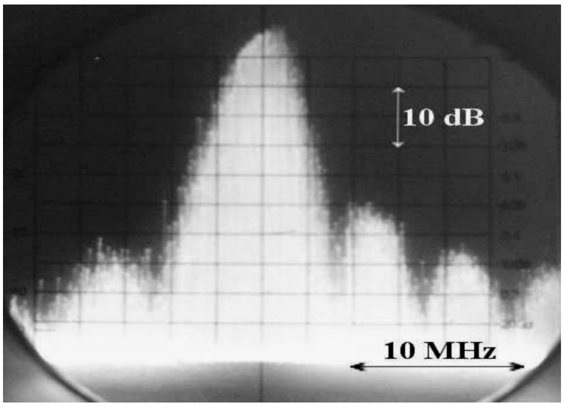

Fig. 3. *Power spectrum of a train of transmitted pulses*

logarithmic scale for the train of pulses with the same length. The level of the first "frequency sidelobe" is about –30 dB, and the spectrum width (between the two first minima) is 2/T, where T is the pulse duration.

The typical characteristics of the transmitters developed for the 36 GHz and 95 GHz Doppler radar systems are given in Table 1.

The operation of the transmitters is controlled by a microprocessor, which provides a smart mode of transmitter operation. In particular, pulse-to-pulse programmed control of the pulse duration and pulse repetition frequency is introduced. Local and remote control of the transmitters is possible.

Table 1. *Parameters of the 36 GHz and 95 GHz Transmitters*

Frequency, GHz	36	95
Output power, kW	30	4
Pulse Duration, ns	50-500	50-400
Duty cycle, max	0.005	0.005
Cooling	Water	Water
Weight, kg	25	25
Power supply, V	220 AC	220 AC
Power consumption, W	700	500

In order to illustrate a high quality of the magnetron transmitters introduced in a 36 GHz radar system, a Doppler spectrum of the signal reflected from a stationary ground-based target located at the distance 12 km is shown in Fig. 4. The delay time of 0.1 s and the pulse repetition frequency of 5 kHz were used in the measurements. It appeared that the spectrum width around zero frequency is 10 Hz, at level –3 dB, and 20 Hz at level –45 dB and it is determined by the dwell time rather than by the phase instabilities of the transmitted pulses. It can also be seen from this figure that the power density in the vicinity of zero frequency is 55 dB higher as compared to that in the other spectral components.

The transmitters described above are used in the recently developed 36 GHz and 95 GHz Dop-

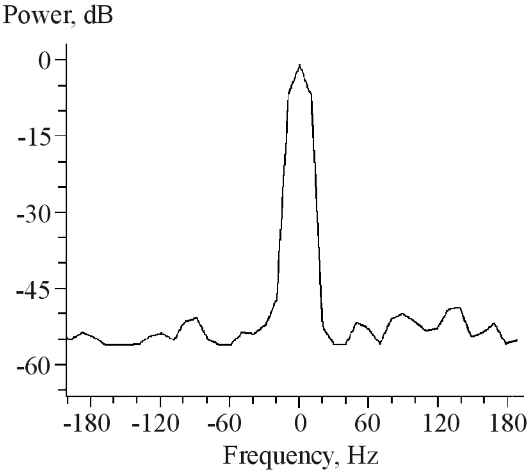

Fig. 4. *Power spectrum of the signal reflected from a stationary ground based target at a distance of 12 km obtained with a 36 GHz Doppler radar*

pler cloud radars [5, 6]. These radars were dopplerized by using a digital coherent receiver technique. The radars were designed for unattended operation, and they provide high-resolution, real-time measurements of the profiles of reflectivity, Doppler spectrum, mean radial velocity, and velocity variance.

4. Conclusion

In this paper, we have made the first report on the millimeter-wave transmitters based on the spatial-harmonic magnetrons with a cold secondary-emission cathode for applied coherent radar systems. The results demonstrate the advantages of the transmitters such as a high quality of transmitting pulses, including a high pulse-to-pulse frequency stability, small intrapulse phase variation, and negligibly small jitter. The transmitters for the frequencies of 36 GHz and 95 GHz with the power level of 30 kW and 4 kW, respectively, have been developed and successfully implemented in Doppler cloud profiling radars.

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Магнетронные передатчики для когерентных радиолокационных систем миллиметрового диапазона

К. Шунеманн, Б. В. Труш, Д. М. Ваврив, В. А. Волков

Магнетроны пространственных гармоник с холодным вторично-эмиссионным катодом применяются в качестве генераторов для радиолокационных систем миллиметрового диапазона длин волн. Подводятся итоги разработок передатчиков, базирующихся на таких магнетронах, и применения их для когерентных радиолокационных систем. Обсуждаются конструктивные решения, принятые для разработки высокоэффективных передатчиков диапазона частот 36 ГГц и 95 ГГц с уровнем импульсной мощности 30 кВт и 4 кВт соответственно. В качестве примера применения описываемых передатчиков рассматриваются метеорологические допплеровские радиолокационные системы.

Магнетронні передавачі для когерентних радіолокаційних систем міліметрового діапазону

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Магнетрони просторових гармонік з холодним вторинно-емісійним катодом застосовуються як генератори для радіолокаційних систем міліметрового діапазону довжин хвиль. Підбиваються підсумки розробок передавачів, що базуються на цих магнетронах, та застосування їх для когерентних радіолокаційних систем. Обговорюються конструктивні рішення, прийняті для розробки високоефективних передавачів діапазону частот 36 ГГц и 95 ГГц з рівнем імпульсної потужности 30 кВт та 4 кВт відповідно. Як приклад застосування подібних передавачів розглядаються метеорологічні доплерівські радіолокаційні системи.