P12.181 THEORETICAL ANALYSIS AND ENGINEERING SOLUTION OF PARASITICAL SPECTRUM IN THE CINRAD TRANSMITTER

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1. INTRODUCTION

Spectrum purity is a key parameter in weather radar test and an important index for estimating radar performance. However, at present there is parasitical spectrum widely existing in the China new generation weather radar (CINRAD) transmitter. Due to complex causes behind the phenomena, this problem has harassed weather radar engineers for a long time in China and hasn't been solved completely yet. In this paper, we establish mathematical models for the parasitical signals and analyze their effect on weather radar performance. Based on the block diagram of CINRAD transmitter, the possible sources of parasitical signals are analyzed in an engineering perspective and a step-by-step method to eliminate parasitical spectrum is presented, which is applied in troubleshooting an experimental weather radar. As a result, parasitical spectrum is basically eliminated and improved spectrum purity and reduced phase noise is achieved.

2. MATHEMATICAL MODELS FOR PARASITICAL SIGNALS AND THEIR EFFECT ON RADAR PERFORMANCE

Normally, a pulsed Doppler weather radar transmits coherent rectangular pulses, whose ideal frequency spectrum is (sinx)/x shaped, symmetrical with carrier frequency (Skolnik, 2003). Actually, due to imperfection in transmitter design along with interference, there is always parasitical spectrum in transmitter output. For simplicity, we will discuss the case of continuous carrier interfered with parasitical signals because pulse modulated spectrum is just to convey carrier spectrum to both sides of pulse spectrum (Qiang Bohan and Wei Zhi, 1985).

2.1. Mathematical Model for Parasitical Amplitude Modulation (AM)

Continuous carrier with parasitical AM can be expressed as (Agilent Technologies, 2001)

$$s(t) = A(1 + m \cdot f(t)) \cdot \cos(2\pi f_c t) \qquad (1)$$

where A and f_c is amplitude and frequency of carrier respectively, $f(t)$ is parasitical signal, m is AM index, usually $|m \cdot f(t)| \ll 1$.

If AM is periodical, that is, $f(t) = \cos(2\pi f_m t)$, then

$$\begin{aligned} s(t) &= A(1 + m \cdot \cos(2\pi f_m t)) \cdot \cos(2\pi f_c t) \\ &= A\cos(2\pi f_c t) + \frac{m \cdot A}{2}\cos\left[2\pi(f_c + f_m)t\right] \qquad (2) \\ &+ \frac{m \cdot A}{2}\cos\left[2\pi(f_c - f_m)t\right] \end{aligned}$$

From (2), we can see parasitical AM spectrum is conveyed to both sides of carrier frequency f_c.

2.2. Mathematical Model for Parasitical Phase Modulation (PM)

Continuous carrier with periodical PM can be

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expressed as

$$s(t) = A\cos\left[2\pi f_c t + \beta \cdot \sin(2\pi f_m t)\right] \quad (3)$$

where β is PM index, f_m is frequency of parasitical PM signal. (3) can be expanded as

$$\begin{aligned} s(t) &= A\cos(2\pi f_c t)\cos\left[\beta \cdot \sin(2\pi f_m t)\right] \\ &- A\sin(2\pi f_c t)\sin\left[\beta \cdot \sin(2\pi f_m t)\right] \end{aligned} \quad (4)$$

Using Fourier series expansion, we get

$$\begin{aligned} &\cos\left[\beta \cdot \sin(2\pi f_m t)\right] = J_0(\beta) \\ &+ 2\sum_{n=1}^{\infty} J_{2n}(\beta)\cos(2n \cdot 2\pi f_m t) \quad t \in (-\infty, +\infty) \end{aligned} \quad (5)$$

$$\begin{aligned} &\sin\left[\beta \cdot \sin(2\pi f_m t)\right] = 2\sum_{n=1}^{\infty} J_{2n-1}(\beta) \cdot \\ &\sin\left[(2n-1) \cdot 2\pi f_m t\right] \quad t \in (-\infty, +\infty) \end{aligned} \quad (6)$$

where $J_n(\beta)$ is Bessel function of the first category. Substituting (5) and (6) into (4),

$$\begin{aligned} s(t) &= A\{J_0(\beta)\cos(2\pi f_c t) \\ &- J_1(\beta)\left[\cos(2\pi(f_c - f_m)t) - \cos(2\pi(f_c + f_m)t)\right] \\ &+ J_2(\beta)\left[\cos(2\pi(f_c - 2f_m)t) + \cos(2\pi(f_c + 2f_m)t)\right] \\ &- J_3(\beta)\left[\cos(2\pi(f_c - 3f_m)t) - \cos(2\pi(f_c + 3f_m)t)\right] \\ &+ \cdots\} \end{aligned} \quad (7)$$

When $\beta < 0.01$,

we have $J_0(\beta) \approx 1$, $J_1(\beta) \approx \beta / 2$, $J_n(\beta) \approx 0$ $n > 1$,

$$\begin{aligned} s(t) &= A\cos(2\pi f_c t) + \frac{\beta \cdot A}{2}\cos(2\pi(f_c + f_m)t) \\ &- \frac{\beta \cdot A}{2}\cos(2\pi(f_c - f_m)t) \end{aligned} \quad (8)$$

Similar to the case of AM, parasitical PM spectrum exists at $f = f_c \pm f_m$. With the increase of β , there are infinite pairs of parasitical spectrum lines distributed at both sides of carrier frequency symmetrically.

In engineering, both AM and PM parasitical interference may be present in signals transmitted by radar.

2.3. Effect of Parasitical Signals on Weather Radar Performance

First of all, spectrum purity of transmitted signal is reduced, possibly leading to false target detection. Especially when the amplitude of parasitical spectrum is comparable to that of useful signal, parasitical spectrum may be regarded as target echo, which in fact is spurious.

Second, in case of parasitical PM, the power of carrier frequency will decrease, causing a loss of signal-to-noise ratio, resulting in reduced accuracy for power estimate and reflectivity measurement.

Third, according to the mean velocity estimator obtained by pulse pair processing algorithm (Passarelli and Siggia, 1983, Doviak and Zrnic, 1993),

$$\hat{v} = \frac{\lambda}{4\pi} \cdot \frac{\arg \hat{R}(T)}{T} \quad (9)$$

where $\hat{R}(T)$ is the autocorrelation at a sample time lag T (pulse repetition time or PRT). Obviously, parasitical PM will bias signal phase and thus bias mean velocity estimate.

Fourth, parasitical spectrum increases phase noise of radar system and hence deteriorates system coherency. Moreover, according to approximate relation between phase noise α and ground clutter suppression capability L (Ge Runsheng and Liu Enqing, 1989),

$$L = -20\lg(\sin\alpha) \quad (10)$$

increased phase noise will degrade ground clutter suppression capability of radar system.

3. ENGINEERING ANALYSIS FOR THE SOURCES OF PARASITICAL SIGNALS

The simplified block diagram for CINRAD transmitter is shown in Fig.1.

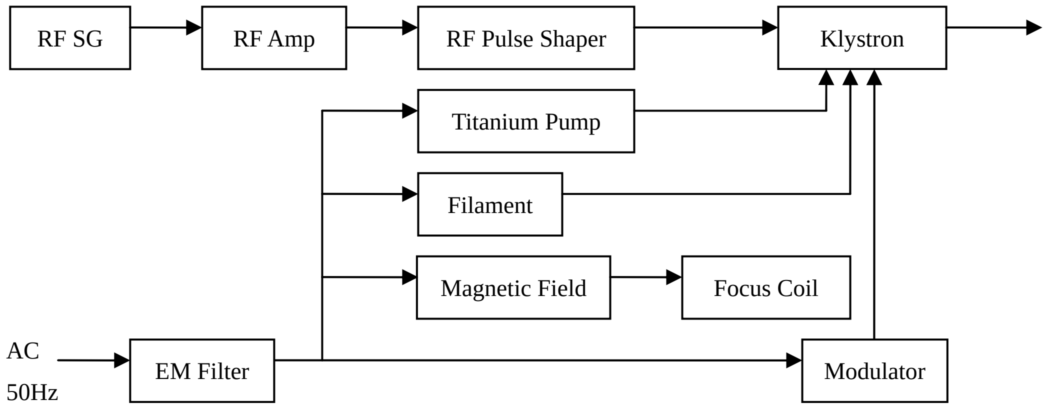


Fig.1. Simplified block diagram for CINRAD transmitter

RF input signal from signal generator (SG) passes through RF amplifier and RF pulse shaper, and then is amplified by klystron and transmitted by antenna. As Fig.1 shows, CINRAD transmitter can be divided into RF input channel, klystron, modulator and power supply. All of these four parts can be sources of parasitical signals, which are analyzed in an engineering perspective as follows.

(1) Parasitical signals may exist in RF input channel consisting of RF signal generator, RF amplifier and RF pulse shaper, eventually enter klystron and be transmitted.

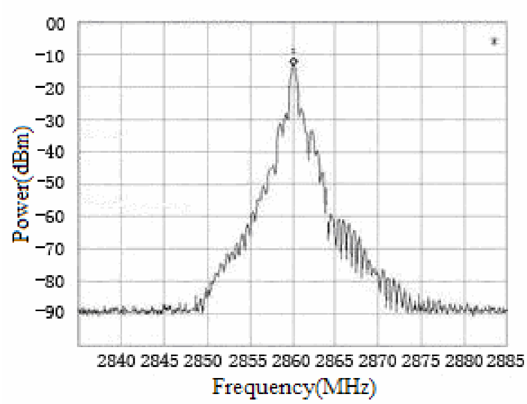
(2) Chambers in klystron are not tuned in to the RF input signal frequency.

(3) Rising and falling edges of klystron cathode modulation pulse make electron beam produce additional velocity and density modulation, resulting in additional phase modulation (Xie Jialin and Zhao Yongxiang, 1966).

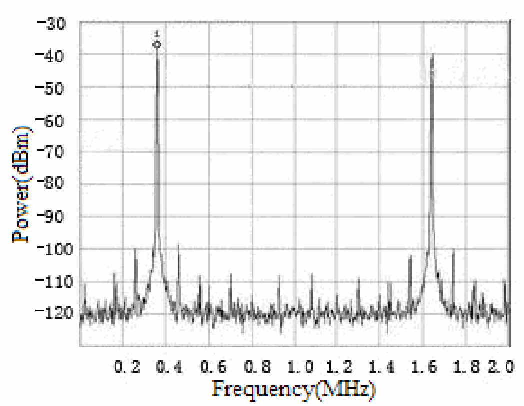
(4) Working frequency for filament power supply and radar pulse repetition frequency(PRF) are not synchronous. In addition, ripple wave produced by power supply of 50Hz is not fully eliminated by electromagnetic filter, and then is mixed into klystron.

(5) Mechanical vibration produced by cooling blowers and fans leads to loose RF cable connection and results in RF leakage power, which is amplified by klystron.

(6) High voltage cable is close to signal wire. If loaded, high voltage will produce powerful current which stimulates strong magnetic field, interfering with signal wire.



a)



b)

Fig.2. Frequency spectrum of CINRAD transmitter output before debugging (a) (RBW = 30kHz, VBW = 30kHz, Sweeptime=1s). (b) (RBW = 3Hz, VBW = 3Hz, Sweeptime=642.9ms).

4. METHODS TO ELIMINATE PARASITICAL SIGNALS AND EXPERIMENT RESULTS

The experimental CINRAD transmitter output frequency spectrum is shown as Fig.2.

In the experiment, carrier frequency $f_c = 2860MHz$. In Fig.2a, frequency spectrum analyzer is set as RBW = 30kHz, VBW = 30kHz, Sweeptime=1s; In Fig.2b, RBW = 3Hz, VBW = 3Hz, Sweeptime=642.9ms. As is shown in Fig.2a, there is obvious asymmetry with carrier frequency for transmitter output spectrum. In high resolution mode, Fig.2b shows that several pairs of parasitical spectrum lines exist at both sides of transmitted pulse spectrum.

According to analysis of Fig.1, the transmitter is debugged step by step as follows.

Step1: Measure frequency spectrum of klystron input port. If there is no parasitical spectrum, then no parasitical signal exists in the RF input channel. Otherwise examine output spectrum of RF signal generator, RF amplifier and RF pulse shaper sequentially until module containing parasitical signals is located and replaced.

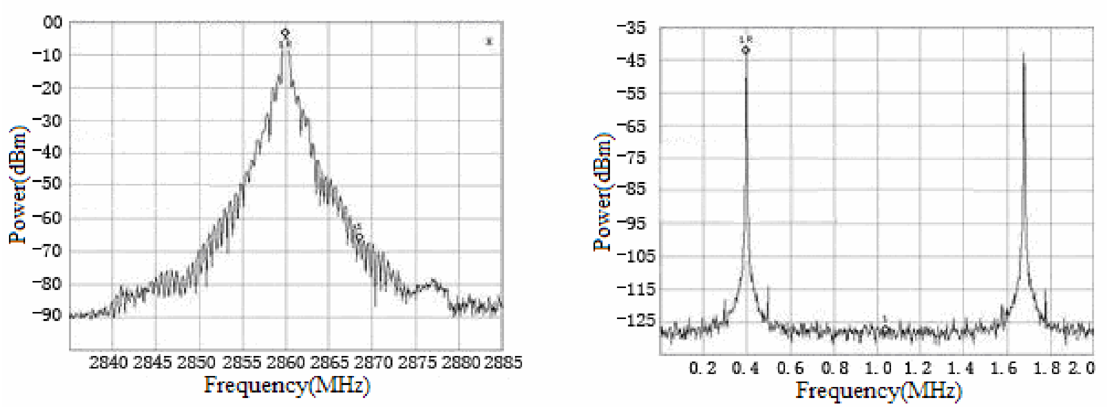
Step2: Adjust the klystron chambers to ensure all of them are tuned in to the transmitted frequency so that klystron input pulse signal can obtain maximum gain.

Step3: Chronologically, RF input signal should be introduced during the stable level of klystron cathode modulation pulse, that is, RF input pulse should be narrower than modulation pulse and be encompassed in it completely.

Step4: Adjust synchronization circuit in the filament power supply in order that its working frequency is synchronized with radar PRF.

Step5: Switch off power supply of klystron blower, focus coil blower and oil pump and fasten RF cable connectors.

Step6: Cable layout is adjusted so that high voltage cable and signal wire is separated.



a) b)

Fig.3. Frequency spectrum of CINRAD transmitter output after debugging (a) (RBW = 30kHz, VBW = 30kHz, Sweeptime=1s). (b) (RBW = 3Hz, VBW = 3Hz, Sweeptime=642.9ms).

Eventually, debugged frequency spectrum of transmitter output is shown in Fig.3. Settings in Fig.3a and Fig.3b are the same as Fig.2a and Fig.2b respectively. Fig.3a indicates spectrum is symmetrical with carrier frequency. Fig.3b shows parasitical spectrum lines are basically eliminated, only with a pair of residual spectrum lines located at 100Hz away from transmitted pulse spectrum, which might be caused by ripple wave from power supply of 50Hz.

5. CONCLUSIONS

To deal with the universal problem that there is parasitical frequency spectrum in the CINRAD transmitter, this paper establishes mathematical models for the parasitical signals existing in radar transmitter and analyzes their effect on weather radar performance. Based on an engineering analysis of their possible sources, we present a step-by-step method to eliminate parasitical spectrum, which is used in troubleshooting an experimental Doppler weather radar. Eventually, parasitical spectrum is basically eliminated. As a result, spectrum purity is improved and phase noise is reduced. Moreover, accuracy for velocity estimate as well as ground clutter suppression ability of the radar system is enhanced. In engineering, parasitical signals are caused by numerous factors that can't be enumerated completely in the paper. Moreover, their sources and impact on weather radar performance require further exploration.

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