Frequency standard distribution via a microwave communication system

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In order to implement a precision frequency offset system in a television transmitter network, each radio-frequency carrier must be very stable and accurate. One way of achieving this is to distribute a reference signal (e.g. from a rubidium or caesium frequency standard at the studio centre) to each transmitter site. This signal can then be used to "steer" the locally-generated carrier with great stability and accuracy.

This article describes the system developed by RTV Slovenija to distribute such a reference signal via the existing microwave programme distribution network in Slovenia.

1. Introduction

The frequency ranges assigned to terrestrial television are becoming more and more saturated, leading to increased levels of adjacent-channel and, in particular, co-channel interference (CCI).

This interference can be minimized by:

- carefully choosing the transmission frequency, taking into account the geographical characteristics of the location;
- carefully designing the antenna radiation pattern at each location;
- using a normal frequency offset;
- using a precision frequency offset.

Broadcasters such as RTV Slovenija usually have no control over the choice of frequency, transmitter location, antenna radiation pattern and normal frequency offset, which leaves just one technique they can use to minimize co-channel interference – *precision frequency offsets*.

2. Precision frequency offset system

The subjective effect of screen patterns produced by CCI is related to the line structure of the television picture. It is possible for these patterns to be made less objectionable by offsetting the carrier frequency of one or more transmitters in the network by an amount[1] that is related to the television line frequency. This implies, however, that greater attention must be given to the frequency stability of the RF carrier.

1. The frequency offset can be positive or negative. It is usually a specific multiple of $^{1}/_{12} \times$ television line frequency.

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If a precision frequency offset system is to be implemented, the expected protection from CCI will only be realized if certain requirements are fulfilled:

– all transmitters included in the system should have a stabilized carrier frequency which is within 1 Hz of the nominal value;

– the frequency offset of each transmitter should have been defined in advance.

A precise reference signal must be available at each transmitter site to stabilize the frequency of not just one but, perhaps, several carriers which are to be included in the precision frequency offset system. The required level of accuracy can only be achieved by using a caesium or rubidium standard, which is too expensive to install at every site where a stabilized carrier frequency is required.

3. The RTV Slovenija solution

In 1994, there were about 15 television main transmitter sites in Slovenia, linked together by a microwave communication system. A precise reference signal was needed at all these sites, so that a precision frequency offset system could be implemented. At some sites, the stable signal from the DCF77 long-wave transmitter could have been used: its carrier frequency (77.5 kHz) is controlled by a caesium standard. However this solution would have been rather expensive to adopt universally, as the local oscillator of each transmitter would have required a secondary frequency standard, and a special receiver would have been needed at each site – a receiver which is immune to different disturbances (atmospheric noise, the combination products of powerful electromagnetic fields near transmitters, etc.).

RTV Slovenija concluded that the most economical solution would be to distribute a very accurate reference signal – derived from a centrally-located rubidium standard – to each of its main transmitter sites. There, the reference signal would be used to “steer” the carrier frequency of those transmitters which were to be included in the precision offset system.

The distribution system chosen to transport the reference signal had to comply with the following conditions:

– it should essentially be cheaper than all other solutions considered to date;

– its reliability should not be below that of other systems;

– it should be independent of outside sources;

– transmitter carrier frequencies should be no less accurate than if they were being steered directly by a rubidium standard.

3.1. 9023-kHz pilot frequency

After several years of study, it was found that the most appropriate way of delivering a frequency standard signal to each main transmitter site would be to use the existing microwave television distribution system. According to the ITU-R, a 9023-kHz pilot frequency may be inserted on this type of distribution system, to enable automatic switching to a spare link in the event of a fault condition [1]. Additional stabilization of the 9023-kHz pilot, and its use for other purposes, has no adverse affect on the sound and vision signals or, indeed, on the automatic switching system itself.

The use of the 9023-kHz pilot for frequency standard distribution would have some advantages over other systems:

– it is transmitted continuously as a sine wave;

– it can easily be extracted by means of an appropriate filter;

– it can be transmitted in a package along with the vision and sound signals;

– the system reliability can be even higher if the pilot signal is transmitted via two or more microwave links simultaneously.

To make our proposed system really work, the stable 10 MHz output signal from a rubidium (or caesium) reference standard would need to be converted into the 9023-kHz frequency required by the pilot. After microwave distribution to each transmitter site, the 9023-kHz signal would have to be separated from the vision/sound package and converted back into a precision 10-MHz signal which could be used to steer the transmitter carriers. The precision pilot system which has been installed by RTV Slovenija is now described.

3.2. 10 MHz / 9023 kHz frequency conversion

With reference to *Fig. 1*, a rubidium (or caesium) reference signal is converted from 10 MHz to 9023 kHz by a frequency converter which we have designed ourselves at RTV Slovenija. Its characteristics meet all the aforementioned requirements regarding vision and sound degradation. It also has some other important characteristics:

– the frequency and phase stability of the 9023-kHz signal is practically the same as that of the source 10-MHz signal;

– conversion is performed without the use of a secondary frequency standard and without additional oscillators (thus the conversion is instantaneous).

– if the 10-MHz reference source is interrupted, there is a simultaneous interruption to the 9023-kHz pilot signal (and when the 10-MHz signal reappears, the 9023-kHz signal reappears instantaneously).

It is very simple to service the 10 MHz / 9023 kHz frequency converter; all that is required is an oscilloscope which operates up to at least 20 MHz.

As we may want to route the 9023-kHz signal to two or more microwave links, a distribution amplifier with six outputs is included in the system. In the case of microwave link systems which were not designed to carry a pilot signal, a coupler is required to add the 9023-kHz signal to the baseband vision and sound signals.

The minimum aim of RTV Slovenija is to stabilize the carrier frequency of the main transmitters in its two television networks; this involves distributing the 9023-kHz signal via two microwave links. However, in practice, the 9023-kHz pilot is routed to five microwave links, thus enabling the carrier frequency of all its main radio transmitters to be stabilized as well.

3.3. 9023 kHz / 10 MHz frequency conversion

At each transmitter site, it is necessary to separate the 9023-kHz pilot from the incoming vision and sound signals and to convert it back into a reference signal at 10 MHz. For this purpose, RTV Slovenija has developed a device which has practically the same characteristics as the 10 MHz / 9023 kHz frequency converter.

Commercially-available television transmitters usually include input ports for different standard frequencies (1 MHz, 5 MHz or 10 MHz). Consequently, our system includes a distribution amplifier which provides a number of outputs at these three standard frequencies.

3.4. System measurements

Table 1 shows the results of frequency measurements made on seven different transmitters, Tx 1 to Tx 7, whose characteristics are given in *Table 2*. The frequency measurements were carried out by means of a Rohde & Schwarz ESVP measuring receiver, steered by a 10-MHz rubidium frequency standard. All measurements were performed at a resolution of 0.1 Hz.

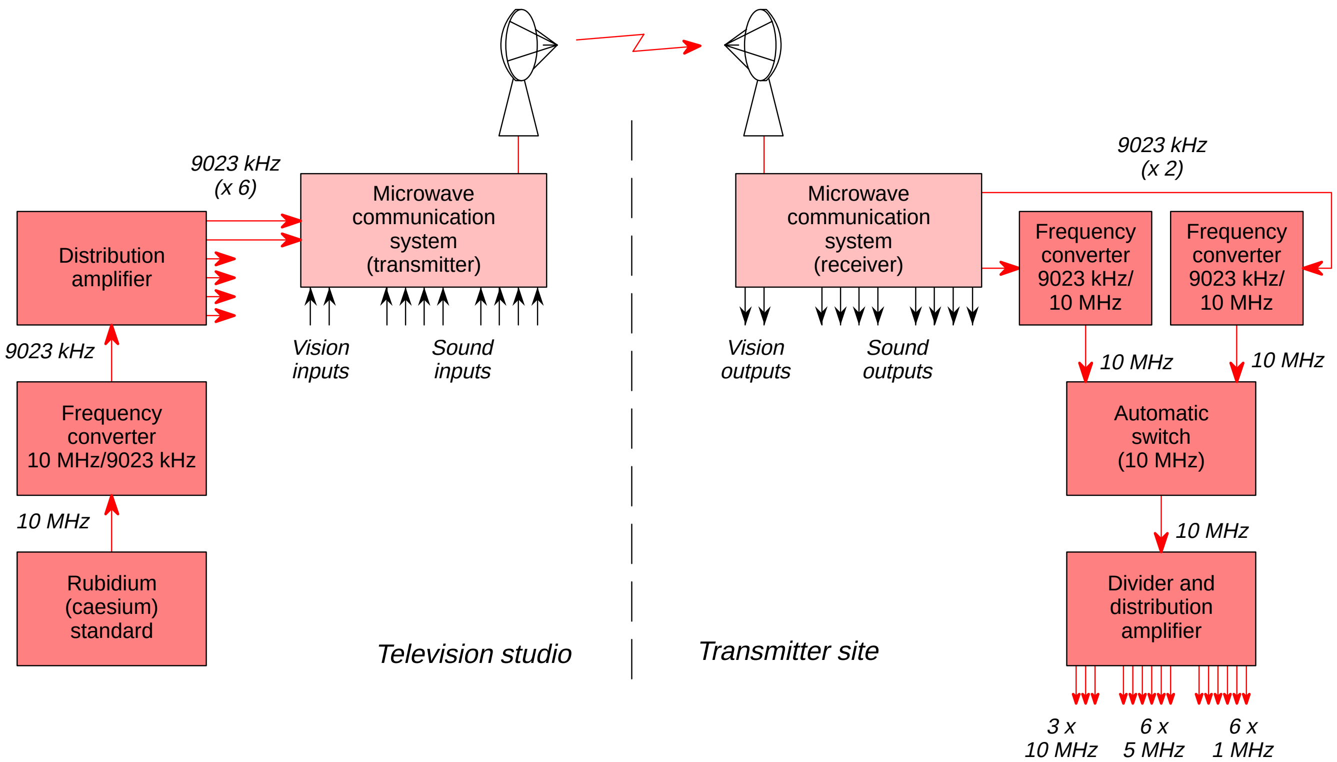

Figure 1
RTV Slovenija's microwave communication system with high-stability 9023-kHz pilot.

Four of the transmitters, Tx 1 to Tx 4, were steered by RTV Slovenija's precision 9023-kHz pilot, distributed via its microwave communication network. Transmitter Tx 5 was steered by the 77.5-kHz signal from the DCF77 longwave transmitter. For comparison purposes, measurements were also carried out on two Austrian transmitters, Tx 6 and Tx 7, which are steered by a rubidium frequency standard.

We are very happy to report that the frequency stability of our 9023-kHz pilot system is completely equivalent to that of the other high-accuracy systems we have evaluated.

Time (min)	Tx 1 (Hz)	Tx 2 (Hz)	Tx 3 (Hz)	Tx 4 (Hz)	Tx 5 (Hz)	Tx 6 (Hz)	Tx 7 (Hz)
01	–0.7	+0.0	–0.1	+0.2	–0.1	–0.1	–0.1
02	+0.1	+0.0	+0.0	+0.0	–0.4	+0.0	+0.0
03	+0.0	+0.1	+0.0	+0.0	–0.2	–0.1	–0.1
04	+0.0	+0.1	–0.1	+0.0	–0.3	+0.0	+0.0
05	–0.1	+0.0	+0.0	–0.1	–0.2	+0.0	–0.1
06	+0.1	+0.0	+0.1	+0.0	–0.3	–0.1	+0.0
07	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
08	+0.0	+0.0	+0.0	+0.1	–0.1	+0.0	–0.1
09	+0.1	+0.0	+0.1	+0.1	+0.2	–.01	+0.0
10	+0.0	+0.1	–0.1	+0.0	+0.0	+0.0	+0.0
11	+0.1	+0.0	+0.0	–0.1	+0.3	–0.1	+0.0
12	+0.0	+0.0	+0.0	+0.0	+0.6	+0.0	–0.1
13	+0.0	+0.0	+0.0	+0.0	+0.5	+0.0	+0.0
14	+0.1	–0.1	+0.0	+0.1	+0.4	–0.1	–0.1
15	+0.0	+0.0	–0.1	+0.0	+0.3	+0.0	–0.1
16	+0.0	–0.1	+0.1	–0.1	+0.1	–0.1	+0.0
17	+0.0	+0.0	+0.0	+0.0	–0.2	+0.0	–0.1
18	+0.0	+0.0	+0.0	+0.0	+0.0	–0.1	+0.0
19	+0.1	+0.0	+0.0	+0.0	+0.1	–0.1	+0.0
20	+0.0	–0.1	+0.0	+0.0	–0.2	+0.0	+0.0
21	+0.0	+0.0	+0.1	+0.1	+0.0	+0.0	–0.1
22	+0.0	+0.0	+0.0	+0.0	+0.3	–0.3	+0.0
23	+0.0	+0.0	+0.0	+0.1	+0.1	+0.0	+0.0
24	+0.0	+0.0	–0.1	+0.0	+0.1	+0.0	–0.0
25	+0.0	+0.0	+0.0	–0.1	–0.3	–0.1	–0.1
26	+0.0	+0.0	+0.0	+0.0	–0.4	+0.0	+0.0
27	+0.1	+0.0	–0.1	–0.1	+0.2	+0.0	+0.0
28	+0.1	–0.1	+0.1	+0.0	+0.0	–0.1	+0.0
29	+0.0	+0.0	+0.1	+0.0	+0.1	+0.0	+0.0
30	+0.0	–0.1	+0.0	+0.0	+0.7	+0.0	–0.1

Table 1
Measurements made on the seven transmitters labelled Tx 1 to Tx 7 over a period of 30 minutes (see *Table 2).*

Tx	Site	Freq. (MHz)	Frequency standard
Tx 1	Beli Kriz	671.25	9023 kHz
Tx 2	Pohorje	217.25	9023 kHz
Tx 3	Kuk	511.25	9023 kHz
Tx 4	Trdinov vrh	217.25	9023 kHz
Tx 5	Plesivec	182.2396	DCF77 LW Tx
Tx 6	Schoeckl	189.25	Rubidium
Tx 7	Schoeckl	487.25	Rubidium

Table 2
Location and frequency information on the seven transmitters used for the measurements (see *Table 1*).

4. *Universal transmitter interface*

Most standard versions of a television transmitter enable only a normal frequency offset system to be implemented (this allows the carrier to deviate from its nominal frequency by up to 500 Hz over a period of six months). If we want to implement a precision frequency offset system, the transmitter carrier frequency must be further stabilized. This generally means that a special type of transmitter must be used which provides input ports for various reference frequencies (1 MHz, 5 MHz or 10 MHz). When purchasing such a transmitter, the following requirements should be taken into consideration:

– if an external reference frequency is not connected, the transmitter should operate without interruptions in the normal frequency offset mode;

– if an external reference frequency is connected, the transmitter should operate continuously with the frequency accuracy provided by the external source;

– if the external frequency is interrupted for a certain period of time, the transmitter should not be interrupted although it will now operate with reduced carrier accuracy (and when the external source appears again, the carrier frequency stability should once again equal that of the external reference);

– when connecting an external frequency, the vision and sound quality should not be impaired and no intermodulation products should be generated.

Most of our older transmitters did not have a port for an external reference signal. As this equipment had come from a number of manufacturers, a variety of interfaces would have been needed to synchronize their carrier frequencies to the external

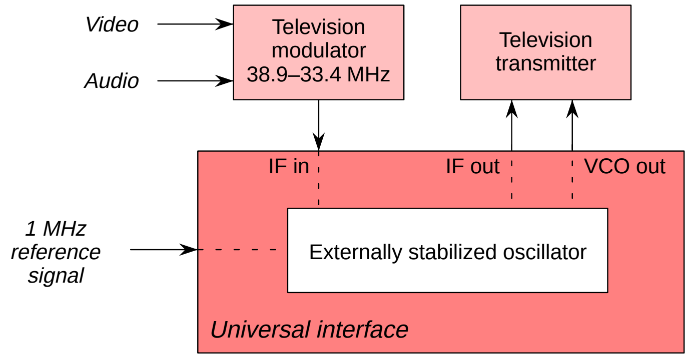

Figure 2
Television transmitter with universal interface.

source. Such a solution would have been very expensive, so we chose another solution. We tried to purchase a universal, reasonably-priced interface which did not require the transmitter to be altered or its carrier-steering circuits to be replaced.

In the event, it was not possible to find such an interface, so we assembled one ourselves from sub-assemblies available on the market in Slovenia.

This interface meets all our requirements:

– no alteration of the transmitter is necessary although its oscillator has to be replaced by the externally-stabilized oscillator built into the interface;

– the interface does not change the transmitter parameters;

– if the 1-MHz reference signal is lost, the transmitter switches without interruption to the normal frequency offset mode;

– when the 1-MHz reference signal reappears, the transmitter switches without interruption to the precision frequency offset mode.

Fig. 2 shows how the interface is connected to the transmitter.

5. Further developments

The frequency standard system described here is suitable for use only at television and radio transmitter sites which are connected to a microwave communication system. As the frequency spectrum available for television becomes more and more occupied, so it will become necessary to include more and more transposers into the precision frequency offset system (we have about 200 television transposers in Slovenia). This gives rise to two big problems:

– the precision reference signal must be delivered economically to each transposer site where it is required;

– the universal interface must be adapted to suit the different types of transposer used in the transmission chain.

The cheapest way to deliver the reference signal to transposer sites would be to send the precision 9023-kHz pilot via one of our satellite channels. At each transposer site, the pilot could be filtered out from the baseband signal and converted into a 10-MHz reference signal.

Another more-expensive possibility is to use the 19-kHz pilot radiated by VHF/FM stereo transmitters. In this case, a secondary frequency standard – with a sufficiently short-term and long-term frequency stability – would be needed at each transposer site.

Either solution would ensure that a precision reference signal is also available at any other locations in Slovenia which are covered by the chosen mode of distribution (satellite, VHF/FM).

Bibliography

[1] ITU–R Recommendation F.401-2: **Frequencies and deviations of continuity pilots for frequency modulation radio-relay systems for television and telephony**.

Mr. Anton Emersic *graduated as an Electrical Engineer in 1964 from the University of Ljubljana (Republic of Slovenia) and then joined RTV Slovenija. Initially, he was involved in building up and maintaining the television transmitter network in Slovenia, but has also been involved in the development of radio broadcasting networks in Slovenia.*

Mr. Emersic has specialized in transmitter antenna systems and in the development and introduction of precision frequency offsets. For a few years, he was a part-time lecturer in a secondary technical school in Ljubljana.