# A NEW DEVICE FOR COMMUNICATION SYSTEMS

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## Introduction

In the Government it is often desirable for a communication system to provide additional features other than the normal transfer of information from point to point. These additional features may be any or all of the following:

1. Provides distance between the transmitter and the receiver (communication ranging)

2. Provides locations of the transmitter or receiver (communication navigation)

3. Provides operation in a common frequency allocation in a manner which allows multiple user communications (random multiple access)

4. Provides user identification

5. Provides Doppler shift correction (correction of frequency offset, induced by differential velocities of moving transmitter or receivers)

6. Provides tolerance to external interference.

In order to provide these features the communication system must have a special modulation structure. Phase coherent frequency-hopping (FH) modulation is a prime candidate technique for providing a multiple feature, flexible communication system. The Phase Coherent Frequency Synthesizer, recently developed by Page and the Naval Research Laboratory, provides the modulation source for such a communication system. This paper will describe this type of synthesizer and its system uses.

## Synthesizer Description

A frequency synthesizer is a single generator that produces any one of a multitude of possible signals. Each signal or frequency is precisely controlled, and the control is usually in steps rather than being infinitely variable. The frequency and the duration of the frequency period can be locally or remotely controlled. Figure 1 shows a frequency synthesizer in its simplest form.

The two basic characteristics of the Phase Coherent Frequency Synthesizer which make it different from the more common industrial variety synthesizers are its phase/frequency coherence and its fast switching or phase setting time. These two characteristics allow the synthesizer to produce combined phase and frequency-hopping modulated signals.

An explanation of the operation of the Phase Coherent Frequency Synthesizer must first begin with a definition of "phase coherent frequency." Phase coherent frequency is defined as a frequency that has phase continuation from one appearance to another. An example of this type of coherence would be a frequency standard that has its output switched on and off in alternate fashion. Each time the frequency appears at the output of the switch, its phase is the same as if the switch had remained in the closed position (Fig. 2). The word "phase" means relative position of the signal (usually measured in degrees). This coherency also requires that the multiple synthesizer output frequencies are all separated by exactly the same frequency, and the phases are all related to a common frequency source; in this case, an internal or external frequency standard. This means if the source frequency is changed by a certain percent frequency or phase, all output frequencies will change by that same percent. The precision of the frequency separation is proportional to the stability of the frequency standard and the quality of the synthesizer design.

The Phase Coherent Frequency Synthesizer can be generally described by the following characteristics [1]:

1. Dual modulation capability (phase and frequency Hopping)

2. 256 VHF output frequencies (television RF spectrum)

3. Fast frequency hopping

4. Ultrafast transitions from one frequency period to the next.

5. Ultrasmall component of noise contained on the output frequency

6. Ultrastable frequency steps

7. Ultrastable frequency repeatability

8. Phase continuity from one frequency appearance to its following appearances (coherence)

9. Local and remote control of phase, frequency, frequency-hopping rate, phase rate, and frequency or phase duration period.

If you had a super television set at some time in the future that had 256 channels that had to be switched from channel to channel at the frame rate for reception, your television might have a coherent synthesizer for tuner local oscillator.

The 256 frequencies are generated by multiplying the outputs for two groups of 16 oscillators, each of which is referenced back to the internal frequency standard. Each of these groups supplies 1 of 16 possible outputs. The 1 of 16 selection process is provided by a 16-pole electronic switch and is controlled by either a random encoder, front panel switches, or a remote source (computer). Thus, the 16-by-16 cross-matrix of stable frequency sources produces 256 output frequencies by using all combinations of the matrix. A simple block diagram of a Phase Coherent Frequency Synthesizer is shown in Figure 3.

A simple analog of the Phase Coherent Frequency Synthesizer would be a 256-position, single-arm switch connected to 256 different frequency standards. Each of the standards would be referenced or locked to a common frequency standard. The switch could jump from one position to any other position almost instantaneously. The mechanism which controls the switch position time is also locked to a reference frequency standard. The output of the synthesizer is the arm of the switch.

## Synthesizer Features

The Phase Coherent Frequency Synthesizer, when properly incorporated into a communication system, will be able to provide normal communications plus the following characteristics:

1. Noise resistance

2. Multiple users in common bandwidth

3. User identification

4. Ranging (transmitter to receiver distance measurement)

5. Navigation

6. Doppler (motion-induced frequency distortion) correction

7. Communication privacy.

The noise tolerance or resistance is provided when a narrow-band data signal is spread over a wide bandwidth. The information rate of transfer is reduced while signal reception quality increases when FH modulation is used to spread the data bandwidth. This is a very important characteristic for types of communication where there is a possibility that some outside source will try to intentionally confuse the system receiver with fictitious signals. The civil police, the FBI, and various government agencies will all have requirements for this type of reliable communications.

The sequences in which the various synthesizer output frequencies are arranged can be made to be unique or different from one another. This characteristic allows each user to be assigned a particular sequence which cannot be confused with one of the other system user's sequences. When the receiver is set to accept a certain input sequence and data are received at that setting, the receiving operator knows for certain that the incoming data are from the desired party (user). The number of users the system can support is proportional to the number of different synthesizer frequencies that are available. Thus, the system's coded frequency sequence provide multiple-user operation, user identification, and communication privacy.

The ranging or distance measuring feature of the FH communication system can be provided by measuring the time required for a signal to traverse from the transmitter to the receiver (simplex mode) or from the transmitter to the receiver and back to the transmitter (transpond mode). A coded sequence is the time identifier. In the transpond mode, the time is measured between the first-sequence appearance at the transmitter and second-sequence appearance at a colocated receiver. The third appearance of this sequence can be made sufficiently long so as not to be a consideration. The accuracy of the time measurement, and, thus, the distance measurement, is enhanced by the coherent feature of the signal structure. Figure 4 shows the conventional pulse-to-pulse ranging operation versus the coherent waveform ranging operation. The conventional measurement is degraded by the variation in the receiver's signal shape and width. The coherent technique makes an average measurement over the individual cycles of the carrier. This provides higher resolution and therefore greater accuracy.

Navigation data can be extracted from the coherent FH system by means of the same features that are used for ranging. The system that requires navigational data and has the restriction of omnidirectional antennas or all-direction antennas must perform range measurements from several points of observation. These multiple range data are used to plot circles of possible location. The intersection of the multiple circles provides the location of the specific transmitter. The minimum requirement would be three observation points in a triangular sector. Two points may be used if additional location information (such as forward or backward direction data) is available. Single reference-point direction-finding systems require rotating directional antennas or a multitude of antennas forming a circular array.

The coherent feature of the FH also provides an aid to correcting frequency offset distortion. This distortion occurs in a communication link when the transmitter and receiver are in relative motion and is attributed to the Doppler effect. Since all the frequency periods are phase continuous and phase related, a phase comparison of every frequency period can be used to correct the common clock. This is not possible if the system frequency source (the synthesizer) is noncoherent.

## Synthesizer Application

A typical incorporation of the synthesizer into a communication system is shown in Figure 5. At the transmitter the synthesizer serves as data to RF signal-converting device. Its output is amplified and, in some cases, raised in frequency and then applied to the transmit antenna. At the receiver the synthesizer serves as the local oscillator. The RF receiver, the intermediate frequency (IF) decoder circuit, and the signal synchronizer circuit work in conjunction with the synthesizer to derive the data which were originally put into the sýstem at the transmitter.

When the coherent synthesizer is incorporated in a FH/phase modulation system, the resultant feature allows a wide variety of system applications. The noise tolerance feature increases the effective signal-to-noise margin at the receiver. This feature will allow a system to:

1. Operate with more noise and interference than a common system

2. Operate with increased system range (communication distance) when the interfering noise is not present, or

3. Operate over a communication link with more path impairments (multipath, rain attenuation, etc.) than that which is possible with a common system.

These characteristics are necessary for top priority communication channels.

Communication satellites which are designated as repeating devices are particularly prone to external interference. As the earth's communication activity and spectrum crowding grow, satellite communications will experience larger amounts of man-made interference. The use of a coherent FH system can considerably improve the tolerance to this interference.

Phase-coherent FH modulation could also find use as an emergency backup communication system for air-traffic control. This backup system would come into operation when adverse communication conditions arise. The coherent FH modulation system in this application would be set to operate in the noise tolerance mode. This operation takes a narrow bandwidth signal and spreads the signal over a wide bandwidth (on RF spectrum). This trades off a reduction in the data rate for improving the effective signal strength at the receiver and thus overcomes external noise, self-interference, and poor transmitting conditions.

The multiple-user and user-identification features can be used in an application where a common communication point must talk to a squadron of men, a group of mobile vehicles or a group of aircraft or individuals within the latter groups. These features allow specific communication to one individual, blanking out all others. These are very common requirements.

The ranging and navigation features of the described system are required in applications where the communication uses are in strange or nebulous environments and require direction or homing information. Examples of this are ship/aircraft in a heavy fog or men in a thick jungle. Additional applications of these features are aircraft collision avoidance, automated landing in crowded airports, and tracking of suspicious individuals via planted transmitters.

## Possible Civilian or Commercial Uses

There are a number of future industrial, commercial, and civil communication systems which may utilize Phase Coherent Frequency Synthesizers and coherent FH modulation. The most prominent of these uses would be the commercial airlines air-traffic communications and police communications.

Air traffic is increasing on a yearly basis. The amount of data transfer between the aircraft and to and from the aircraft and ground is also ever increasing. These two conditions will cause new frequency channels to be required (more RF spectrum) and also cause pressure to improve the quality and efficiency of the communication systems.

Presently commercial air-traffic control communications normally incorporate a combination of human intelligence, frequency modulation communication, and radar to perform the required control and regulation functions. The future improved communication systems will have the human intelligence aided or replaced by computers, while the communications and control functions will probably be combined into an integrated system. Phase-coherent frequency hopping may form a portion of this future integrated system.

The future civil and commercial air-traffic control communication systems must provide an effective collision avoidance mechanism, an automated aircraft landing capability, an automated route setting capability, and digitized voice/data communications. This must be provided within a reasonable bandwidth. These requirements can be met by some combination of the coherent FH modulation and timesharing [2].

As crime, especially syndicate crime, grows in the U.S., the law enforcement bodies may be required to utilize sophisticated communication equipment to deter the criminal element's attempt to interrupt the police signals. Future law enforcement communications will, in most likelihood, also require: (1) message privacy, (2) multiple user (total and individual) operation, (3) user identification, (4) location information for tracking cars or individuals (range/navigation operation). A form of coherent FH modulation and its companion coherent synthesizer may be incorporated in future law enforcement communications to provide the above requirements.

## Conclusions

A new communication device and modulation capability have been developed for the transmission of digital data or voices from point to point. This device is a fast-switching Phase Coherent Frequency Synthesizer. When this synthesizer is appropriately incorporated in a communication system it can provide interference resistance, multiple-user capability, user identification, ranging, navigation, Doppler correction, and digitized communication (voice and data). This device may find extensive use in specific government communication systems which have a need for the above features. If this device and its corresponding communication system are successful for the government, civil and commercial application of similar devices and systems is very likely to take place. The prime areas of civil and commercial application are future communications for law enforcement bodies and for the aircraft/airport complex. The future law enforcement bodies' communications can take advantage of the FH system's noise tolerance, multiple user capability, and user identification features primarily, and the ranging and navigational features secondarily. The future commercial aircraft communication can take advantage of all the FH system's features for combined communication navigations, collision avoidance, automated landing, and automated route-setting. Thus, the same or similar types of communication systems that serve government satellite-to-ground or aircraft-to-ground links may also serve for the corresponding civil or commercial counterparts. In conclusion, we can say that the Phase Coherent Frequency Synthesizer and corresponding FH modulation are examples of a governmental communication development that may well benefit the average man in the street.

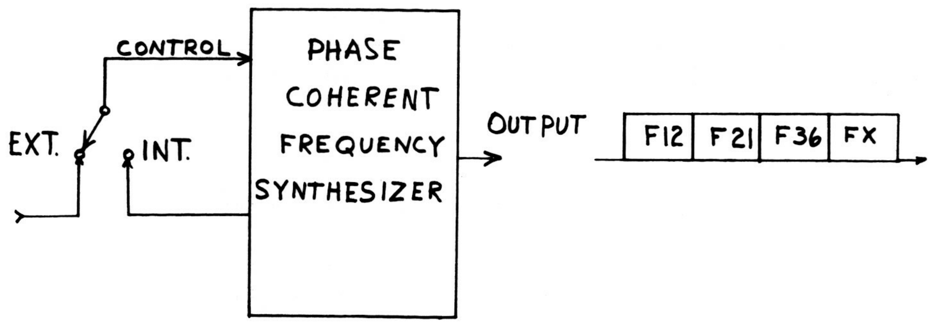


Figure 1. Phase Coherent Frequency Synthesizer, simplified.

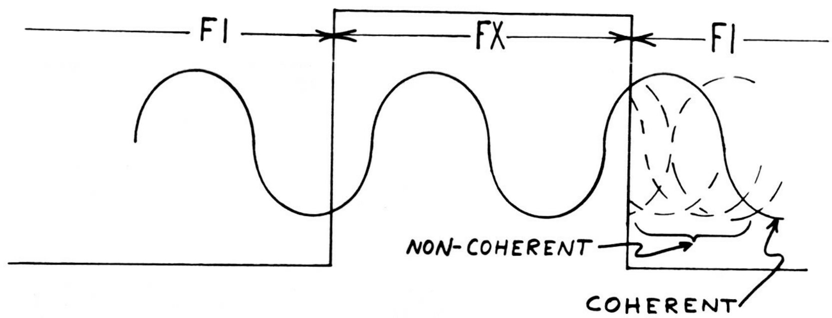


Figure 2. Phase coherent frequency switching.

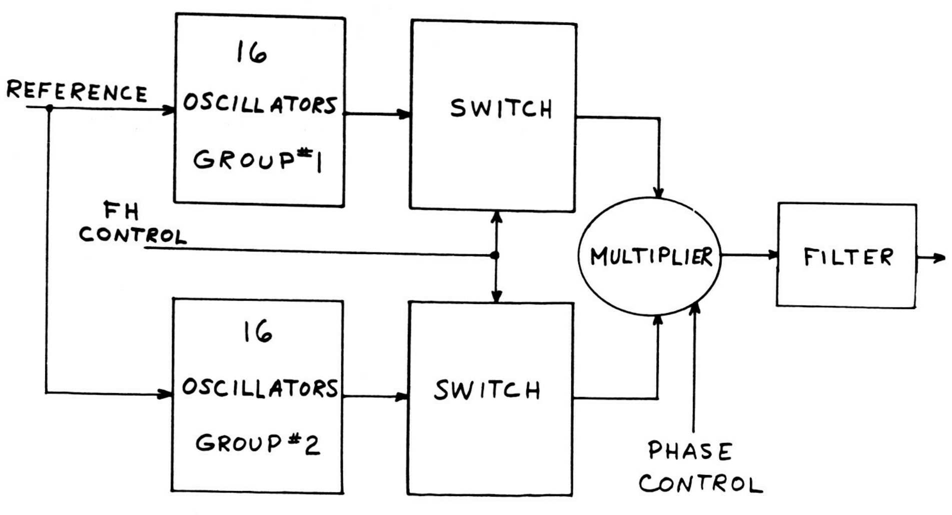


Figure 3. Simplified block diagram of the Phase Coherent Frequency Synthesizer.

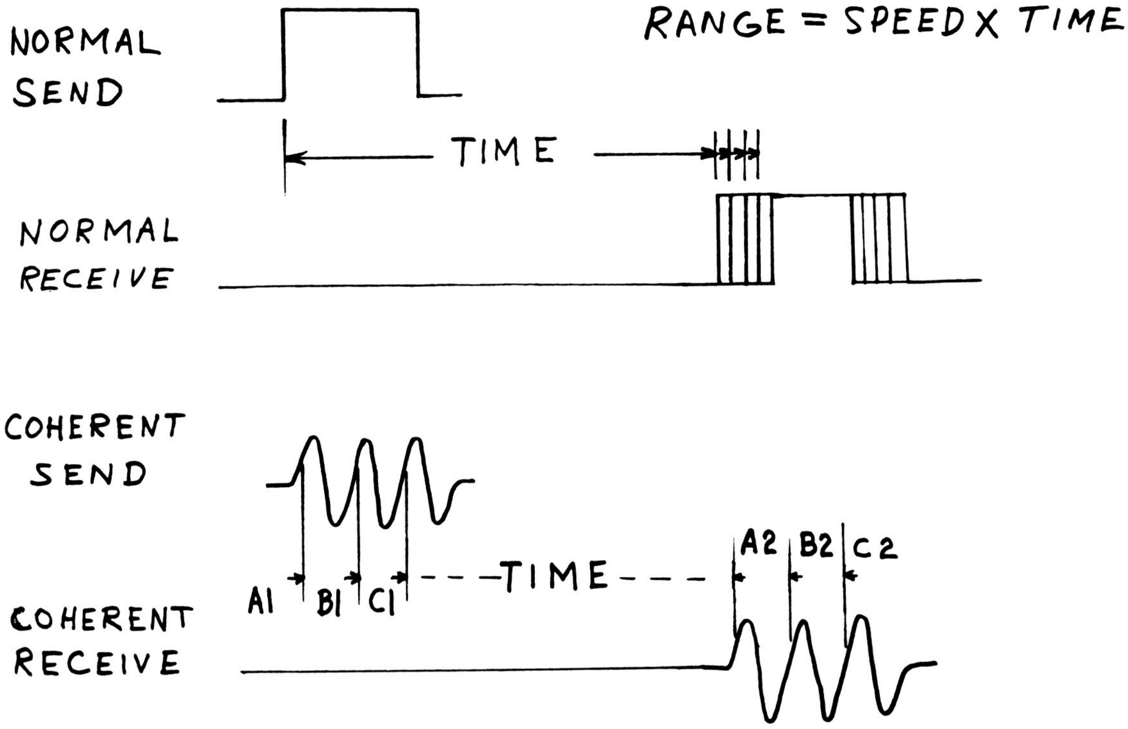


Figure 4. Noncoherent versus coherent ranging.

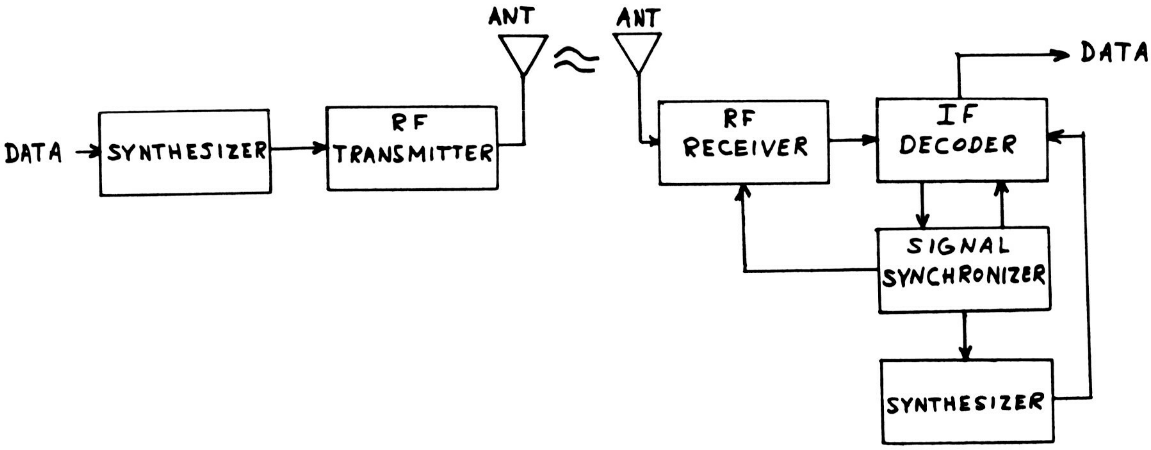


Figure 5. A simplified FH system with synthesizers.